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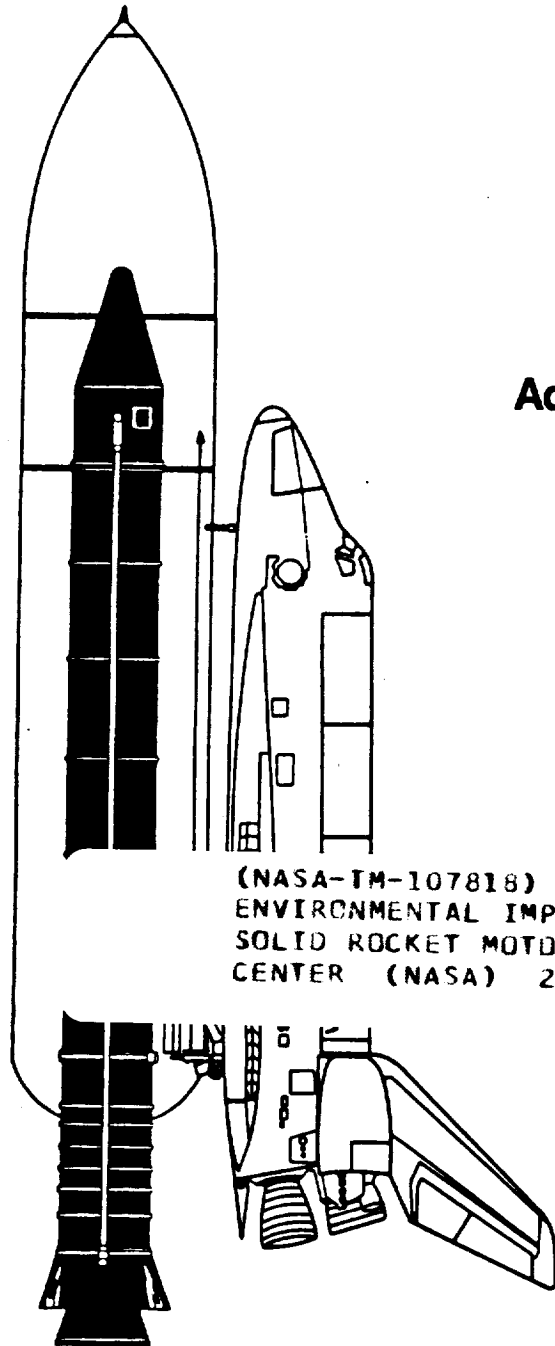
SUPPLEMENTAL

FINAL

Environmental Impact Statement

Space Shuttle

Advanced Solid Rocket Motor Program



(NASA-TM-107818) SUPPLEMENTAL FINAL
ENVIRONMENTAL IMPACT STATEMENT FOR ADVANCED
SOLID ROCKET MOTOR TESTING AT STENNIS SPACE
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John C. Stennis Space Center
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SUPPLEMENTAL FINAL ENVIRONMENTAL IMPACT STATEMENT FOR ADVANCED SOLID ROCKET MOTOR TESTING AT STENNIS SPACE CENTER

() Draft (X) Supplemental Final Environmental Impact Statement

RESPONSIBLE FEDERAL AGENCY:

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BRIEF DESCRIPTION OF ACTION:

The proposed action is construction and operation of test facilities, and testing the Advanced Solid Rocket Motor (ASRM) which will replace the motors currently used to launch the Space Shuttle. Construction will include (1) a barge/dock facility; (2) a test firing stand and associated buildings and support facilities; and (3) access roads and a transporter road to move the ASRM from the barge dock to the test stand. The test program will consist of up to 4 tests per year for 30 years. The Final Environmental Impact Statement (FEIS) and Record of Decision on the FEIS describing the potential impacts to human health and the environment associated with the program and documenting first the preference for and then the final selection of Stennis Space Center (SSC) as the test site for ASRM were issued in March and April 1989, respectively. Since publication of the FEIS, three factors have caused NASA to initiate additional studies regarding the potential for health or environmental impacts associated with the ASRM program. These factors are: (1) the U.S. Army Corps of Engineers and the Environmental Protection Agency (EPA) agreed to use the same comprehensive procedures to identify and delineate wetlands; (2) EPA has given NASA further guidance on how best to simulate the exhaust plume from the ASRM testing through computer modeling, enabling more realistic analysis of emission impacts; and (3) public concerns have been raised concerning short- and long-term impacts on human health and the environment from ASRM testing. This Supplemental Final Environmental Impact Statement (SFEIS) addresses each of these factors.

SUMMARY OF ENVIRONMENTAL EFFECTS:

The final ASRM test site selected reflects the minimum possible impact to the wetlands at SSC. Where impacts to wetlands cannot be avoided, mitigation must be provided to the extent possible. Wetlands temporarily affected by construction will be allowed to return to their natural state. The determination of loss for wetlands permanently affected will be based on the functions they serve, such as fish and wildlife habitat and flood control. The functional values of such wetlands will be replaced. The improved predictions supported by field observations of the exhaust plume dispersion indicated the ultimate concentration at ground level of the products of concern (hydrogen chloride and aluminum oxide) would be less than originally predicted in the FEIS. This assessment shows that potential exposure to these exhaust products should not cause any adverse effects on humans. The analysis provided in this SFEIS also supports the findings in the FEIS that, given the naturally occurring conditions of the environment in the area of SSC, no harm to aquatic species, wildlife, plants, soils, groundwater, or surface water as a result of ASRM testing is expected.

SUBMITTAL DATE:

The Supplemental Final Environmental Impact Statement (SFEIS) was submitted to the Environmental Protection Agency for the Notice of Availability to appear in the Federal Register on or about August 17, 1990. The SFEIS will be released to the public immediately after filing the document with the EPA.

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EXECUTIVE SUMMARY

PROJECT SUMMARY

Stennis Space Center (SSC) in Hancock County, MS has been selected as the site for testing the Advanced Solid Rocket Motor (ASRM), a redesigned motor for the Space Shuttle which will greatly improve flight safety, reliability, and performance. Testing the ASRM at SSC will involve construction of (1) a barge/dock facility on the existing Access Canal; (2) a test firing stand and associated buildings and other ancillary support facilities; and (3) access roads and a heavy duty transporter road to move the ASRM from the barge dock to the test stand. The test area will be located 6.5 miles from the nearest community outside SSC and about 2 miles from most of the workforce at SSC. No more than 4 motors will be tested per year.

BACKGROUND: FINAL ENVIRONMENTAL IMPACT STATEMENT (FEIS)

In March 1989, NASA issued the Final Environmental Impact Statement (FEIS) for the ASRM program. The FEIS indicated NASA's preference for SSC as the test site for ASRM and described the potential impacts associated with the program. The FEIS stated that ASRM testing would not cause any significant impact to the environment or to the health of workers and the general public who live in the vicinity of SSC. In concert with the National Environmental Policy Act (NEPA), NASA solicited public input and comment during the EIS process.

BACKGROUND: SUPPLEMENTAL FINAL ENVIRONMENTAL IMPACT STATEMENT (SFEIS)

Since publication of the FEIS, NASA initiated additional studies regarding the potential for

health or environmental impacts associated with the ASRM program. First, in late March 1989, the U.S. Army Corps of Engineers and Environmental Protection Agency (EPA) agreed to use the same comprehensive procedures to identify and delineate wetlands. Using these guidelines, the EPA evaluated the ASRM project area and determined that much of the designated ASRM test site is wetlands. Given this classification, additional wetlands studies were conducted. In support of the goals of NEPA, NASA is making this information available to the public as a Supplemental FEIS (SFEIS). This SFEIS contains the revised facility layout, describes affected wetlands at SSC, and explains mitigation plans for the affected wetlands.

Further, since publication of the FEIS, documentation of the plume dispersion predictions for the Space Shuttle Redesigned Solid Rocket Motor static test program used in the air emissions permit in Utah became available. The prediction or modeling method used in 1989 was recommended by EPA Region 8 and reviewed and concurred in by the State of Utah. That permit action set the first regulatory precedent for predicting dispersion of exhaust products from solid rocket motors similar to the size and performance characteristics of the ASRM. The prediction method was a combination of the model used in the ASRM FEIS to predict exhaust product composition, quantities, and stabilization altitude and dimensions of the exhaust cloud, followed by a "puff" model, more familiar to the EPA, to project dispersion of the exhaust products. The revised prediction method was used to prepare the Prevention of Significant Deterioration (PSD) air emissions permit application submitted to the Mississippi Bureau of Pollution Control. A comparison of predicted impacts generated from the method used in the permit application to the FEIS is presented in the SFEIS.

Finally, the SFEIS directly responds to public concerns raised subsequent to the release of the FEIS. These include both short- and long-term impacts of ASRM testing on human health, aquatic species, wildlife, water, vegetation, and soils.

WETLANDS

Using the new federal guidance, EPA identified how much of the site area would be classified as wetlands. Because such a large portion of SSC is wetland, it was impossible not to have the ASRM test area affect wetlands. Therefore, a permit called a "404 Permit" is required from the U.S. Army Corps of Engineers prior to any construction activities occurring on the wetland areas. An essential part of the decision to grant a 404 Permit is a 401 Water Certification assessed and issued by the Mississippi Bureau of Pollution Control.

Between January and June 1990, NASA modified the initial ASRM site facility design and refined the road layout so the project would minimize the physical and functional loss of wetlands. Using this revised site design, construction or primary impacts to wetlands, which represent permanent loss, were identified. Construction of the ASRM facility will require clearing and filling a maximum area of 69 acres of wetlands. An additional 243 acres of wetland will only need to be cleared of trees and other large woody species.

Wetlands have a number of important biological, hydrological, social, and economic functions. These functional values include flood control; stormwater, sediment, and pollution control; surface water supply; groundwater recharge/discharge; providing fish and wildlife habitat; and providing education, recreation, and open space. The quality of a wetland is generally evaluated in terms of the quality and importance of its functions, and may not be related to its size. In addition to identifying the types of wetlands that would be affected or filled for the ASRM project,

further studies included an assessment of the wetland's functional value. NASA sought to minimize the overall impact to wetland areas, but especially to the most valuable wetland habitats. For the ASRM program, approximately 90 percent of the affected wetland area is pine-savannah, with the remainder primarily consisting of bottomland hardwood forest. The preliminary functional value analysis of the wetlands to be affected (filled) by this project are biotic and hydrologic in character. The primary biological function of the pine-savannah is wildlife habitat. The principal hydrologic functions of the wetlands to be affected are flood storage and breakup of storm flow. Both of these functional values have been reduced by commercial forest management of the area and construction of extensive drainage ditch systems.

NASA will avoid all major pitcher plant concentrations or bogs during construction because these bogs are unique wetland communities which are disappearing regionally from the pine-savannahs largely as a result of commercial plantation forestry. Some individual pitcher plants scattered throughout the site cannot be avoided. However, by avoiding the major concentrations of pitcher plants, NASA will help keep its commitment to protecting this unique and diminishing habitat.

Mitigation or compensation for the wetland acres that are filled will consist of three methods: (1) restoration of the hydrologic functions by filling ditches in pine-savannah areas and building low berms across selected drainage swales; (2) augmentation of bottomland hardwood forest cover for wildlife habitat in pine-savannah areas by discontinuing pine forest management; and (3) enhancement of the unique pitcher plant bog habitat by controlled burning in selected areas. The U.S. Army Corps of Engineers must approve NASA's mitigation plan prior to issuance of the required wetlands permit. The mitigation plan would then be a condition (requirement) of the permit.

AIR QUALITY

The revised modeling or prediction supported by field observations of Space Shuttle solid rocket motor firings in Utah indicates the ultimate concentration of the exhaust products would be less than originally predicted in the FEIS. Each test of an ASRM will generate 127 tons of hydrogen chloride (HCl), 216 tons of particulates (mainly aluminum oxide), and lesser amounts of water vapor, carbon dioxide, carbon monoxide, nitrogen oxides, and aluminum chloride. The total amount of aluminum oxide and other particulate (216 tons) was revised subsequent to issuance of the FEIS and prior to submission of the PSD application in August 1989 because a propellant composition of 16 percent aluminum, and not 19 percent as specified in the final ASRM contract, was used in FEIS modeling predictions. In addition, all chlorine forms such as hydrogen chloride, monatomic chlorine, diatomic chlorine, etc., were totalled and collectively modeled as hydrogen chloride, the acid form, in the PSD application and this SFEIS. This more conservative approach, therefore, results in an increase in the total effective amount of hydrogen chloride used to project potential impacts. The results of this assessment confirm that potential exposure to hydrogen chloride and aluminum oxide to both workers and the public is projected to be well below all federal and state regulatory standards that have been determined to be protective of human health and the environment.

To reduce the concentrations of exhaust products that could fall to the ground or exist in ground-level air concentrations, NASA will build a deflection ramp behind the motor. The ramp is designed to keep soil from being caught up in the exhaust plume and increase the plume's rate of movement and mixing in the atmosphere. However, to be conservative in the exhaust plume dispersion modeling, plume rise predictions were based only on heat rise with no benefit of redirecting the exhaust velocity upward. In the evaluation of "best available control technology," a

number of other techniques for reducing the ground-level concentrations of exhaust emissions were evaluated, including both wet and dry scrubbers. Because scrubber technology is not sufficiently developed on a scale to be effective for ASRM use, the deflection ramp in conjunction with proper weather conditions was determined to be the only feasible "best available control technology."

The exhaust plume from an ASRM static test will rise to a cloud centerline altitude in excess of 10,000 feet. The high humidity of the air around SSC will allow the exhaust cloud to stabilize at altitudes higher than in dryer climates such as Utah. Heat removal from a thermally buoyant cloud is a function of moisture in the air. The higher the moisture in the air, the less heat that can be absorbed for every 100 feet of altitude. Therefore, an exhaust cloud at SSC must rise to a greater height than it would in Utah in order to cool to a temperature equal to the surrounding air.

Unless atmospheric conditions existed at the time of firing that would create a raining cumulus cloud, the exhaust plume-cloud would have no continued source of saturated air and no continuous updraft (two essential conditions necessary to produce rain) after it reaches its final elevation. Therefore, the exhaust cloud will not spontaneously produce a raining cloud. Weather conditions required to form a raining cumulus cloud can be monitored. This information will be used to ensure that testing is conducted under proper meteorological conditions.

In addition, the afternoon mixing height for Jackson, MS (4,261 feet) was used to predict ground-level concentrations of ASRM exhaust products in the PSD permit application and this SFEIS for two reasons. First, the predominant upper-level winds around SSC blow from west to east or from southwest to northeast. Therefore, the plume will be blown toward areas of higher mixing heights than if it were blown to the south.

Afternoon mixing heights of Jackson, MS are approximately 1000 feet higher than those typical of coastal areas such as Mobile, AL. Second, higher mixing heights produce higher ground-level concentrations than lower mixing heights. Using the higher Jackson, MS mixing height, therefore, is a conservative assumption. A complete description of weather conditions and meteorological principles pertinent to the understanding of the behavior of the ASRM exhaust plume in a humid climate is presented in the SFEIS.

In this SFEIS, the test exhaust is modeled under two conditions: (1) no rain for at least two to four hours after test firing, depending on wind speeds (the "expected" condition), and (2) rainfall one hour after the test firing (the "unexpected" condition). The second case is labelled "unexpected" because NASA is committed not to test when rain is predicted within the next two to four hours (depending on wind speed). This case would only occur in the unlikely event that all weather forecasting efforts break down. Modeling these unexpected conditions gives an estimate of the worst possible impacts. The impacts associated with each condition were assessed and are discussed separately in the SFEIS. A summary of those impacts under both conditions appears below.

ENVIRONMENT

"Expected" Conditions

The FEIS stated that, given the naturally occurring conditions of the environment or ecosystem in the area, ASRM testing would not result in any significant impacts to the environment. Using the revised plume dispersion modeling results, the SFEIS further evaluates the potential effects of ASRM emissions on the environment in and around SSC. This further analysis supported the findings in the FEIS that no harm to aquatic species, wildlife, plants, soils, groundwater, or

surface water as a result of the ASRM testing is expected.

Scientific literature was again reviewed and several university and government researchers were consulted concerning topics such as acid rain effects on plants, the neutralizing capability of local soils, and aluminum buildup in soils. These investigations indicated that exposure to the projected concentrations and deposition rates of hydrogen chloride, aluminum oxide, and aluminum chloride under the "no rain" condition are below levels that can cause harm to plants or decrease soil fertility. Therefore, there would be no short- or long-term impacts to plants.

Surface water data were used to characterize various water bodies (creeks, sloughs, bogs, marshes, and wetlands) in terms of their acidity, ability to neutralize additional acid, and presence of aluminum. The data show the waters in and around SSC to be slightly acidic, as expected in southeastern swamps and wetlands. Under "no rain" conditions, no measurable acid fallout is expected and there would be no acidity impact to surface waters from ASRM testing. Aluminum concentrations are predicted to increase by very small amounts, and not in sufficient quantities to upset the existing natural balance of the surface water.

Relevant studies of the effects of aluminum compounds and hydrogen chloride on aquatic species were thoroughly reviewed. Based on the modeling and projected deposition patterns and resulting concentrations of hydrogen chloride and aluminum over present background levels, no impact to aquatic species in the SSC vicinity is expected.

Possible effects on wildlife and domestic animals were also reevaluated using relevant scientific literature and consultations with university and government researchers. This assessment indicates that projected ground-level air concentrations of hydrogen chloride following testing of

the ASRM are 100 to 200 times below the injury level observed in research on small animals. Aluminum oxide is projected to be deposited at levels well below the irritation point for wildlife and domestic animals, and will not be absorbed through the skin.

The possibility that ASRM testing might contaminate drinking water wells and/or damage water wells due to vibrations created during testing was also investigated. Scientific literature was reviewed again and local experts were consulted concerning the local geology and groundwater characteristics. This reevaluation confirmed that ASRM testing will not affect groundwater quality in the area. ASRM testing is not projected to contaminate soils or surface water. In addition, other naturally occurring factors exist to prevent groundwater contamination from any source. These include neutralizing of acid by the alkalinity of the groundwater and presence of dense sediments that prevent groundwater flow downward to deeper aquifers.

While ground vibrations will result from ASRM testing, measurements conducted during previous Saturn rocket tests at the site, plus modeling of ASRM-generated ground vibrations show that such ground vibrations will be very small. The ground motion will be reduced to negligible levels within several hundred meters of the test stand, thus avoiding impact on local drinking water wells.

"Unexpected" Conditions

To understand the sensitivity of the environmental impact of ASRM testing, conditions beyond what are ever anticipated to occur were assessed and are described in the SFEIS. Under unexpected and unlikely rain conditions where all weather forecasting efforts totally break down and rainfall occurs soon after a test, most water bodies would not be affected because they have the ability to handle additional acids without changing their natural balance. This ability to

neutralize acid is referred to as buffering capacity. For certain selected, small, shallow surface waters in the vicinity of SSC, there could be short-term effects from rain. These waters would become more acidic for several hours or days, during which time the additional acid would be neutralized. If this condition were to occur, adverse effects to fish and other aquatic organisms would be evident. Increased acidity in small drainages with little buffering capacity could result in localized mortality of aquatic organisms. Conditions at the Red Fish Hatchery near SSC were specifically considered and it was determined that there would be no effect on fish at the hatchery. Plants would be affected by leaf spotting. Aluminum concentrations are predicted to be the same as in the "expected" conditions and therefore are not projected to upset the existing natural balance of the surface water in these areas.

CUMULATIVE EFFECTS

In addition to looking at the possible impacts from each single test firing, the long-term effects of possible accumulation of deposited aluminum oxide and aluminum chlorides from ASRM testing were evaluated. Using the results of the analysis for "expected" test conditions, the accumulated deposition of these components for the 30-year life of the program was calculated by multiplying the quantity of deposited material from each test by 120, a condition described in the PSD permit application. That sum was then distributed in all directions around SSC, according to the percentage of time the wind blows to the east, northeast, north, etc. Because the wind usually blows to the east, most of the deposition was predicted to occur to the east of the test stand. The projected test schedule, however, includes 8 tests in the first 2 years and 2 per year thereafter.

The soils and surface waters will neutralize, transform, and remove most of the deposited material from each test more rapidly than the

material will build up due to the time interval between successive tests. Therefore, the cumulative effects of a maximum of 120 tests over 30 years would be virtually negligible on surface water, groundwater, plants, soils, and aquatic species.

The amount of HCl that would be produced during each ASRM test was compared to the existing level of acid in the atmosphere and the annual emissions of acid gases from all sources (industrial and private) to determine how much ASRM testing would contribute to the existing situation. The findings indicate that the HCl from ASRM testing will contribute a very small amount (less than 0.01 percent) to the total emissions of acid gases from the region around Mississippi.

HUMAN HEALTH

The possibility of long-term effects of HCl, HCl aerosols (mists), aluminum oxide, and aluminum chloride was expressed by the public after the release of the FEIS. The FEIS stated that there would not be any significant impacts. The results of modeling for the PSD permit application and this SFEIS were then used to determine the potential for risk. This assessment shows that potential exposure to hydrogen chloride, aluminum oxide, and aluminum chloride in ASRM emissions should not cause any adverse effects on humans.

A typical human health risk assessment estimates the types and concentration of contaminants; analyzes how humans might be exposed to such contaminants, and the extent and degree of such exposure; determines whether the contaminants are "toxic" and, if so, what level will not cause adverse effects on a daily basis (i.e., levels which EPA or other regulatory agencies determine to be safe); and characterizes the potential for adverse cancer and noncancer health effects to occur. The human health assessment for ASRM follows the basic approach of evaluating what compounds or contaminants exist (in this case the exhaust

emissions) and determining whether or not exposure would cause any adverse effects. Some important modifications to a traditional risk assessment were made because (1) none of the ASRM exhaust products are cancer-causing, and (2) it is not appropriate to estimate daily doses over a 70-year lifetime because potential exposure to ASRM test emissions lasts for a period of 10 minutes to 2 hours, four times per year. Therefore, using the new plume dispersion modeling data along with an analysis of potential chemical interactions between three of the combustion chemicals (HCl, aluminum oxide, and aluminum chloride), the predicted chemical concentrations were compared with the most appropriate air quality standards and guidelines for short-term and daily exposure. These standards and guidelines are developed by federal and state authorities and other specialized advisory groups to protect human health.

Maximum exposure levels to exhaust products will occur in the vicinity of the ASRM test stand. The majority of SSC workers are located at a distance at least 2 miles from the test stand. Prior to and during each ASRM test, all ASRM test workers will be removed to safe distances or into protective buildings. An acoustical buffer zone at least 5 miles wide surrounds the test stand, and the towns nearest the test site are all at least 6.5 miles away.

Maximum concentrations of HCl, aluminum oxide, and aluminum chloride, as well as levels averaged over one hour and 24 hours, were calculated at 0.6, 3, 4.2, 6, and 12 miles from the test stand and then compared to federal and state standards established to protect human health. Maximum 24-hour average concentrations of HCl, aluminum oxide, and aluminum chloride emitted as a result of each test would occur approximately 4.2 miles from the rocket test stand. Based on this analysis, concentrations of all three compounds are projected to be well below established standards and not harmful to workers or to the public.

The maximum HCl concentrations from ASRM testing fall well below the levels documented to cause adverse effects from either short- or long-term exposures. To protect sensitive populations such as infants, children, the elderly, and people with respiratory diseases from HCl emitted during actual Space Shuttle launches, the National Research Council Committee on Toxicology recommended that HCl concentrations averaged over a 1-hour period should not exceed 1.5 mg/m³. The Mississippi Bureau of Pollution Control further limits HCl daily exposure to a 24-hour average of 0.07 mg/m³ to protect the public.

The predicted 1-hour and 24-hour HCl air concentrations at 4.2 miles from the test stand are approximately 10 times lower than either of these guidelines and, therefore, are not considered a health risk to off-site populations. The maximum average 1-hour and 24-hour concentrations predicted at locations from 0.6 to 4.2 miles from the test stand are lower than the predicted concentration at 4.2 miles. Therefore, no adverse health effects to SSC workers from HCl emissions are expected. No long-term effects from HCl emissions for a single event or over the 30-year life of the program are expected because HCl does not accumulate in the body, is controlled by normal body metabolism, and is readily eliminated from the body.

The potential relationship between environmental exposure to aluminum and Alzheimer's disease was addressed through (1) a comprehensive literature search on aluminum and Alzheimer's disease, and (2) a consultant review by recognized medical experts. Samples taken from actual Space Shuttle emissions, and modeling conducted with specific reference to ASRM indicate that aluminum emissions are comprised almost solely of nonfibrous aluminum oxide. The EPA has determined that nonfibrous aluminum oxide is nontoxic. Additionally, in a recent review of aluminum toxicity, EPA found no evidence that supports the theories that aluminum (including aluminum oxide) plays a pathological role (causes

disease) in Alzheimer's disease. The contribution of ASRM emissions to any overall human aluminum intake is limited by two factors: (1) the predicted concentrations of aluminum oxide from ASRM testing are quite low, and (2) aluminum oxide is not readily absorbed into the body. The average daily intake in food and water of all species of aluminum (aluminum oxide, aluminum hydroxide, aluminum chloride, etc.) by persons not exposed to ASRM testing varies between 5 and 50 mg. The predicted 24-hour average concentration of aluminum oxide in the air at 4.2 miles from the ASRM test site equates to a projected maximum total aluminum exposure of 0.002 to 0.008 mg. From all of the modeling and sample monitoring data on the composition of the emissions and the minute quantities projected, along with the information on intake of aluminum oxide, it is concluded that ASRM testing would not cause or increase the risk of Alzheimer's disease or other neurological disorders.

In addition to HCl and aluminum oxide, the SFEIS addresses the possible health effects of other ASRM exhaust products such as aluminum chloride, and the possible production of acid aerosols and acid-coated particles. The formation of aluminum chlorides in the atmosphere after the plume has been emitted from the motor depends upon chemical reactions between the HCl gas, water vapor, and aluminum oxide particles. It is shown that approximately 0.02 percent of the emitted aluminum oxide will be transformed to aluminum chloride when water and HCl are present when the plume is still near the ground. This reaction becomes less likely as the plume rises and the air pressure and temperature drop. Only small amounts of aluminum chloride are expected to be produced as a product of combustion. The amounts emitted represent only about 0.03 percent of all aluminum compounds in the exhaust plume. Because no health risk standard exists for aluminum chlorides, the concentration expected for aluminum chlorides was compared to another compound, HCl, since their irritant toxic properties are similar. Concen-

trations of aluminum chloride were found to be far below the HCl standards set to protect human health.

Little information is available to precisely quantify the amount of HCl aerosol formation from ASRM testing. Therefore, conclusions were drawn regarding the human health impact of HCl-formed acid aerosols by conservatively assuming that all of the HCl gas from ASRM testing forms acid aerosols and that the aerosol level is equal to the point of maximum HCl concentration in air (0.24 mg/m³). This level of HCl-aerosol was then compared to sulfuric acid aerosol which may have similar potential human health effects and on which more information is available. Based on this comprehensive review and assessment, it is concluded that HCl aerosols from ASRM testing should not cause any adverse health effects.

Information on the human health effects of acid-coated aluminum oxide particles, which are found in small amounts in Space Shuttle emissions, is sparse. However, such particles are not projected to form to any great extent and should not result in short- or long-term health effects.

NASA ENVIRONMENTAL ASSURANCE PROGRAM

Underlying the discussion in this SFEIS of potential effects of ASRM testing on human health and the native ecosystem is NASA's commitment to a comprehensive environmental assurance program. This program is designed to ensure that the ASRM static test program at SSC is conducted safely and without damage to human health and the environment. The program will check the assumptions that have been made and the predictions that ASRM will not result in negative impacts. NASA has built in extra measures of safety and protection against uncertainties or unpredicted conditions. An Environmental Assurance Program has been established. Its purpose is to prevent adverse effects to human health and the environment so that damage will

not occur that requires later correction. The program consists of:

- Weather forecasting and monitoring to obtain site-specific atmospheric profiles for predicting plume behavior and dispersion;
- Comprehensive field monitoring of noise levels and ground-level air concentrations of exhaust products during each ASRM test;
- Continuing the verification of air quality predictions by evaluating the realtime data from testing the Space Shuttle Solid Rocket Motors at the Thiokol facility in northern Utah; and
- Establishing a sampling program and regional data base for vegetation, air, soil, rainwater, surface water, and groundwater.

The single most important environmental criterion for testing will be weather conditions. The extensive modeling done for a variety of test conditions shows that it is possible to substantially avoid adverse environmental effects by performing the ASRM tests under certain meteorological conditions. The conditions include minimum wind speeds, conditions that will affect the height to which the plume rises, and conditions that will indicate whether rain is expected within a few hours. The precise meteorological conditions under which testing will take place will be set by the Mississippi Bureau of Pollution Control. Testing only under the prescribed conditions will limit the concentrations of exhaust products in ground-level air concentrations, reduce the deposition of aluminum oxide and aluminum chlorides on the ground, and prevent an increase in the acidity of rainfall.

NASA will establish an on-site weather station and use up-to-the-minute weather information before, during, and after each test to ensure that proper atmospheric conditions are present. Both off-site and on-site weather information will be used.

Testing will not occur if rain is predicted within a minimum of two to four hours of the test, depending on wind speed. NASA will verify the accuracy of this weather forecasting system prior to actual testing by conducting extensive "practice" forecasting. There is sufficient time to do this to assure that the weather conditions for a test can accurately be predicted.

During operation of the project at SSC, comprehensive field monitoring will be undertaken. The amount and chemical characteristics of exhaust products in the air (at ground level) and on the ground will be measured, and noise levels will be determined. This type of information will be the check that everything is consistent with that projected. Monitoring what happens during and after tests is not enough unless current conditions are understood. For this reason, NASA is developing a regional environmental data base for air, soil, groundwater, surface water, rainwater, and vegetation. All of this information will be used to monitor the quality of the environment and ensure that ASRM testing does not cause any harmful effects.

In the unlikely event that this assurance program identifies conditions outside acceptable limits attributable to ASRM testing activities, NASA is committed to suspend testing until the problem is evaluated and corrective measures are developed and approved by appropriate regulatory agencies.

SUMMARY OF ENVIRONMENTAL ASRM EFFECTS

The final ASRM test site selected reflects the minimum possible impact to the wetlands at SSC. Where impacts to wetlands cannot be avoided, mitigation must be provided to the extent possible. Wetlands temporarily affected by construction will be allowed to return to their natural state. The determination of loss for wetlands permanently affected will be based on the functions they serve, such as fish and wildlife habitat and flood control. The functional values of such wetlands will be replaced. The improved predictions supported by field observations of the exhaust plume dispersion indicated the ultimate concentration of the products of concern (HCL and aluminum oxide) would be less than originally predicted in the FEIS. This assessment shows that potential exposure to these exhaust products should not cause any adverse effects on humans. The analysis provided in this SFEIS also supported the findings in the FEIS that, given the naturally occurring conditions of the environment in the area of SSC, no harm to aquatic species, wildlife, plants, soils, groundwater, or surface water as a result of ASRM testing is expected.

GLOSSARY OF ABBREVIATIONS AND STANDARD CONVERSIONS

ACGIH	American Conference of Governmental Industrial Hygienist
ACOE	U.S. Army Corps of Engineers
Al	Aluminum
AlCl ₃	Aluminum Chloride
Al(H ₂ O) ³ (OH) ³	Aluminum Hydroxide
Al ₂ O ₃	Aluminum Oxide
ASRM	Advanced Solid Rocket Motor
BACT	Best Available Control Technology
calories	Energy required to raise 1 gram mass of water 1° C
CEQ	Council on Environment Quality
CFR	Code of Federal Register
Cl	Chlorine
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FEIS	Final Environmental Impact Statement
H ₂ O	Water
HCl	Hydrogen chloride
INPUFF	Puff dispersion model
km	Kilometer
km ²	Square kilometer
KSC	Kennedy Space Center
lbs	Pounds
lb/acre	Pound per acre
m	Meter
m/s	Meter per second

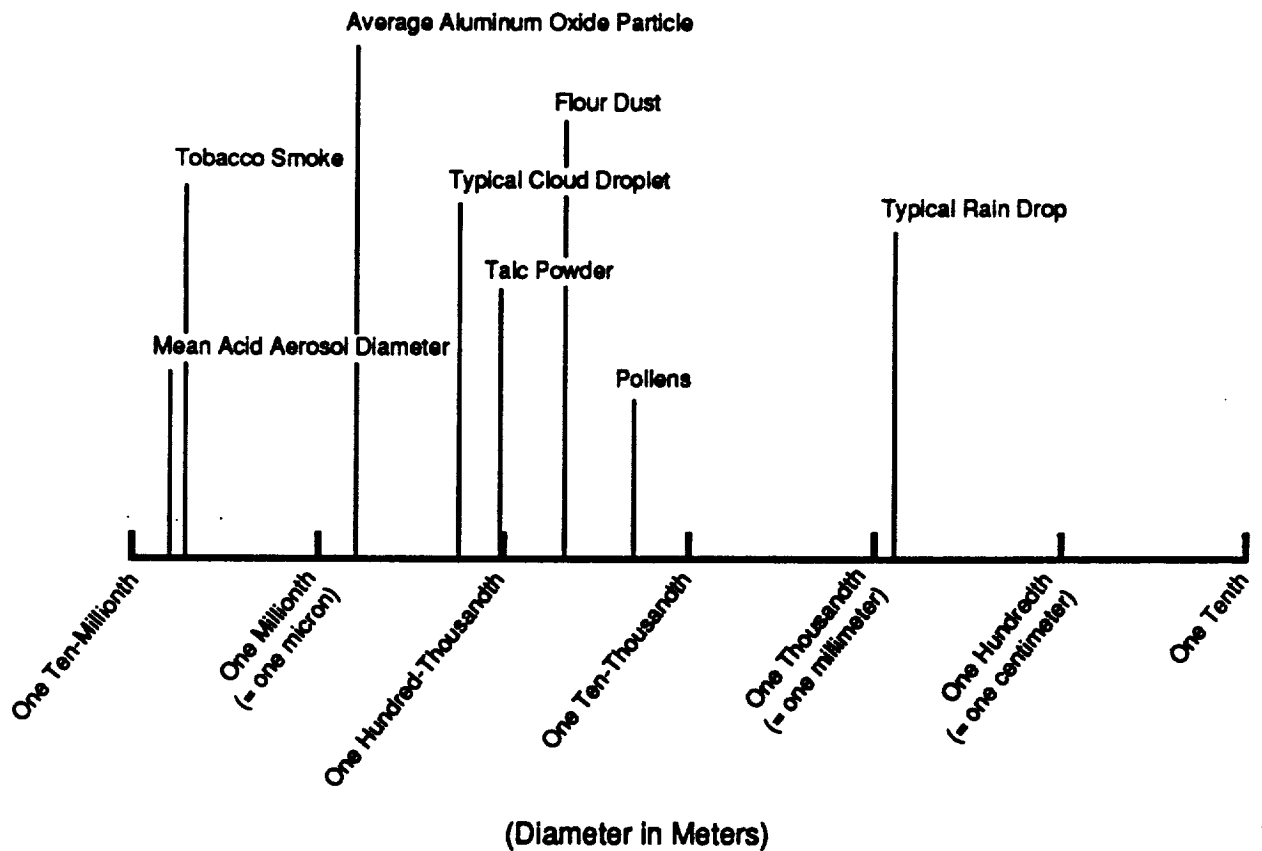
max.	Maximum
MBPC	Mississippi Bureau of Pollution Control
meq/100g	Milliequivalents per 100 grams
mg/L	Milligram per litre
mg/m³	Milligram per cubic meter
mg/m²	Milligram per square meter
mi	Mile
min.	Minimum
mole	Mass numerically equal to molecular weight
MS	Mississippi
µg/L	Micrograms per litre
µg/m³	Microgram per cubic meter
µm	Micrometer or micron (one millionth of a meter; see scale below)
NAAQS	National Ambient Air Quality Standard
NASA	National Aeronautics and Space Administration
NRC	National Research Council
NSTL	National Space Technology Laboratories (see SSC)
OSHA	Occupational Safety and Health Administration
PCAD	Products of Combustion/Atmospheric Dispersion
pH	Measurement of the acidity or alkalinity of an aqueous solution
ppm	Parts per million
PSD	Prevention of Significant Deterioration
SARA	Superfund Amendments and Reauthorization Act
sec	Second
SFEIS	Supplemental Final Environmental Impact Statement
SO₂	Sulfur dioxide
sq. mi.	Square mile
SRM	Solid Rocket Motor

SSC	Stennis Space Center
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

STANDARD CONVERSIONS

mi to km	Multiply by 1.609344
mg to kg	Multiply by 1,000,000 (10^6)
mg to μg	Multiply by 1000
ft to m	Multiply by 0.3048

RELATIVE PARTICLE SIZES



1.0 INTRODUCTION

In March 1989, NASA issued the Final Environmental Impact Statement (FEIS) for the Advanced Solid Rocket Motor (ASRM) Program. The FEIS evaluated ASRM static testing locations at the Kennedy Space Center (KSC) in Florida and at the Stennis Space Center (SSC) in Mississippi. The FEIS indicated NASA's preference to test the ASRM at SSC.

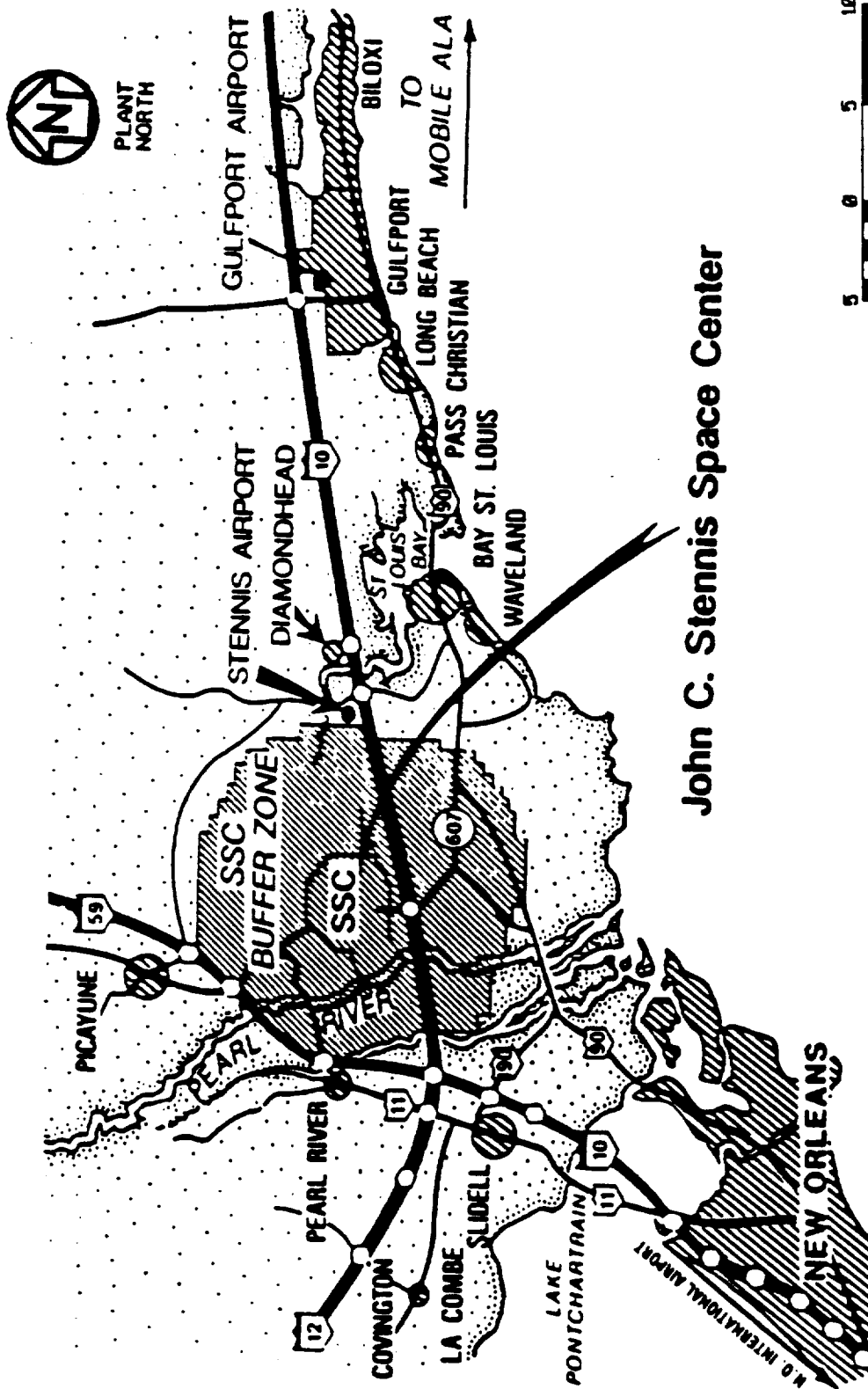
Following publication of the FEIS, NASA began additional work needed so that environmental permits required by state and federal laws could be applied for and received. Specific permit actions undertaken at this time include the following: 1) an application for a Prevention of Significant Deterioration (PSD) permit was submitted to the Mississippi Bureau of Pollution Control in August 1989; 2) an application for a wetlands permit under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act was submitted to the U.S. Army Corps of Engineers (ACOE) in May 1990; 3) the Section 404 permit application submitted to the ACOE will be used by the state of Mississippi to make a water quality determination under Section 401 of the Clean Water Act; and 4) an application to modify SSC's existing National Pollutant Discharge Elimination System (NPDES) wastewater permit was submitted to the Mississippi Bureau of Pollution Control in June 1990.

Subsequent to submittal of the PSD permit application, public concerns were voiced concerning ASRM testing at SSC. These concerns have been noted in local newspapers, at public meetings, and in correspondence. In order to present additional information pertaining to the Section 404 and Section 401 permitting actions, and to address public concerns, NASA is providing this Supplemental Final Environmental Impact Statement (SFEIS). The SFEIS supports the goals of the National Environmental Policy Act (NEPA) and was developed after consultation with the ACOE and the Council on Environmental Quality (CEQ). The CEQ is the executive office which establishes uniform procedures for implementing NEPA and preparing environmental impact statements.

The CEQ guidelines direct federal agencies (such as NASA) to prepare supplements to final environmental impact statements if: 1) there are substantial changes in the project that are relevant to environmental concerns; 2) there is significant new information relevant to environmental concerns; or 3) the agency determines that the purposes of NEPA will be furthered by doing so (40 CFR 1502.9). This SFEIS provides site-specific information addressing a revised facility layout, affected wetlands at SSC, mitigative plans for those affected wetlands, and potential environmental and human health effects from rocket exhaust emissions.

1.1 ASRM PROJECT DESCRIPTION AT SSC

Stennis Space Center and its surrounding acoustical buffer zone are located predominantly in Hancock County, Mississippi (Figure 1-1). The Space Center, located within 12 miles of



John C. Stennis Space Center

NASA

APRIL 27, 1990

GENERAL
LOCATION MAP

Figure 1-1. General location map for the Stennis Space Center.

the Gulf Coast, includes a NASA fee ownership area and an acoustical buffer zone. The fee area, where all NASA-approved institutional and industrial development takes place, occupies approximately 22 square miles. The acoustical buffer zone consists of about 200 square miles extending outward five miles from the fee area perimeter.

The ASRM project facilities will be located in the eastern portion of the fee area at SSC (Figure 1-2). New facilities to be constructed include: 1) a lateral access road, 2) a construction access road, 3) an engineering operations building, 4) a test control center, 5) an equipment storage facility, 6) a barge/dock facility on the existing SSC access canal, 7) a test stand, 8) a heavy duty transporter road to move the ASRM from the barge dock to the test stand, 9) a deflection ramp, and 10) a catchbasin to collect stormwater runoff. A fire safety zone will be cleared around the test stand. Project operation may include testing up to four motors per year. Construction is scheduled to begin in late 1990, with initial testing scheduled in mid-1993. The test stand location is approximately 6.5 miles from the nearest community outside SSC, and approximately 2 miles from most of the workforce at SSC.

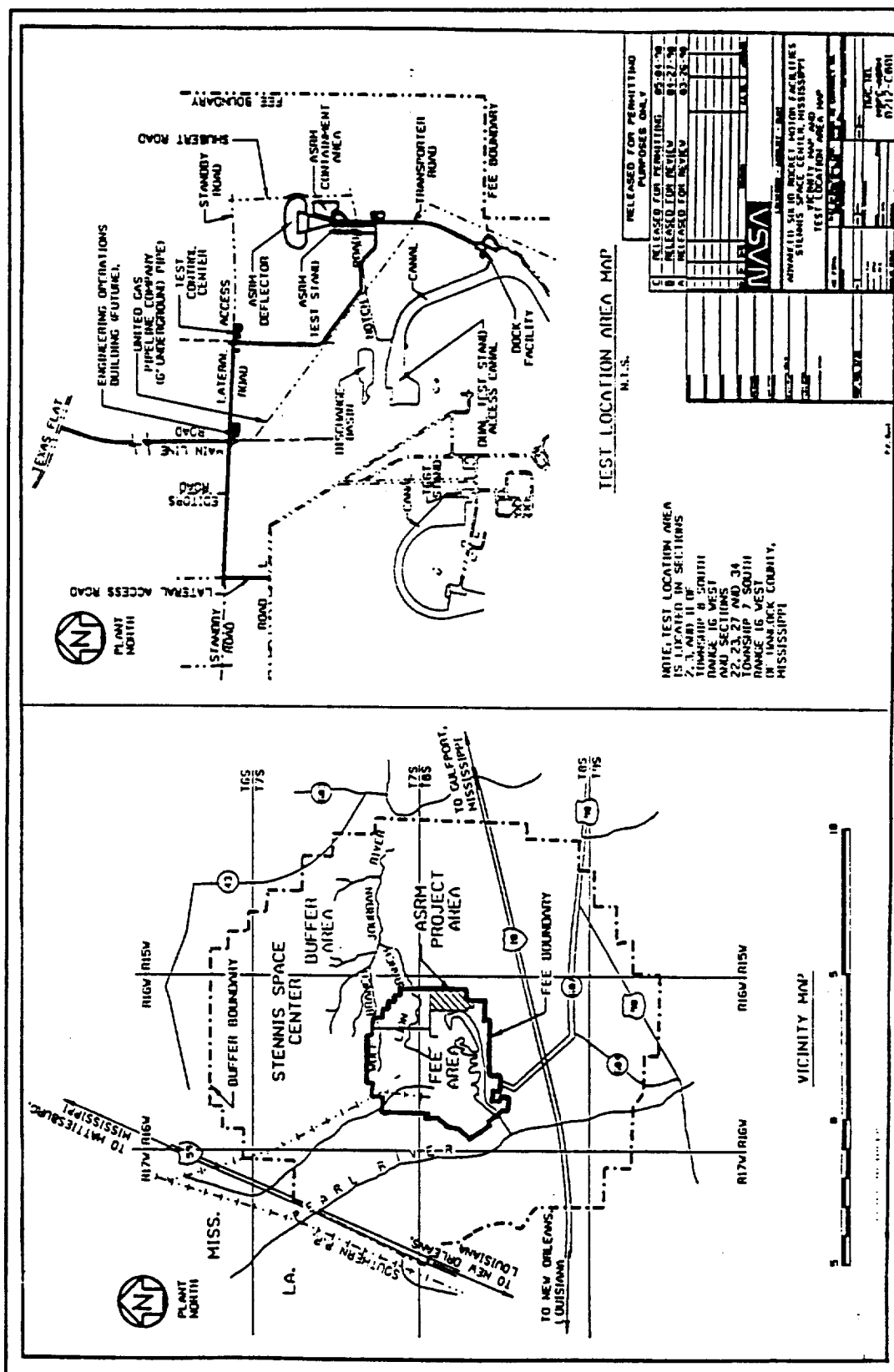
Each test will last about two minutes and will emit combustion products that include aluminum oxide, hydrogen chloride gas, water vapor, carbon dioxide, aluminum chloride, and other constituents. Hot rocket exhaust will extend out horizontally from the test stand before the exhaust loses energy and begins to rise to an altitude of more than 10,000 feet at the plume's centerline. A fire safety zone extending approximately 4,000 feet out from the rocket nozzle and approximately 1,000 feet wide will be cleared of standing vegetation, primarily plantation pine trees. A deflection pad and ramp system will be built on a portion of this cleared safety zone to limit environmental impacts to insignificant levels by deflecting heat, preventing soil and rocks from being caught up in the exhaust plume, and assisting in dispersion of the exhaust plume.

1.2 ENVIRONMENTAL ASSURANCE PROGRAM

In order to safely conduct the ASRM static test program at SSC, NASA is committed to establishing a comprehensive environmental assurance program focused first on prevention of significant environmental impacts, and second, on a monitoring program designed to detect any deviation from predicted conditions. The environmental quality assurance program at SSC will include:

- Meteorological (weather) forecasting and monitoring
- Acoustical (noise) prediction and monitoring
- Air quality prediction and monitoring
- Environmental baseline determination of vegetation, air, soil, rainwater, surface water, and groundwater

To continue validation of models that predict exhaust product concentrations in the air and deposition on the ground, NASA will continue to acquire realtime data from ongoing



static tests of Space Shuttle solid rocket motors at the Thiokol facility in northern Utah. Predicted plume behavior as a function of meteorological conditions will be evaluated and compared to actual results following each test. Updates on information from these efforts will be provided to regulatory authorities and will be available to the public.

NASA will establish a meteorological support group at SSC with state-of-the-art equipment to obtain site-specific atmospheric profiles for predicting plume behavior and dispersion. Forecasting of precipitation will be performed by certified, experienced meteorologists with access to data from the National Weather Service long-range radar system and a high resolution, realtime weather radar system to be installed at SSC.

To verify the accuracy of the weather forecasting system prior to actual testing, NASA will begin extensive "practice" forecasting in 1991. For each practice or simulation, the weather forecasting system will be used to predict meteorological conditions such as cloud coverage, windspeeds, wind direction on the ground and aloft, and probability of rain on the ground and aloft. The forecast will be compared to a set of meteorological criteria that will be established by the Mississippi Bureau of Pollution Control during the PSD permitting process. If the forecast conditions are outside the prescribed limits, a "NO GO" decision will be made, and the practice run will end. If the forecast conditions are within the prescribed criteria, a "GO" decision will be made. A "GO" decision will be followed by a realtime tracking of meteorological conditions in the direction of simulated plume travel to evaluate the accuracy of precipitation forecasting and downwind changes. Results of these simulations will be individually and collectively studied to ensure that all elements necessary for decision-making are fully functional, and personnel are adequately trained and familiar with the equipment to minimize the potential for error and to meet the requirements of the program.

NASA is finalizing plans and beginning baseline data acquisition on the SSC fee area and region surrounding the facility. Aircraft and satellite photography methods, also referred to as remote sensing, will be used to create vegetation maps. Tests will be made to determine the presence and health of fish and other aquatic organisms in local surface waters. Soils and water will be monitored for such parameters as aluminum (total and bioavailable), pH, and buffering capacity. Rainwater will be monitored for pH and acidic compounds. Air will be monitored to measure the presence of particulates. All data will be input into a computerized geographical information system to assimilate this massive data base and retrieve and analyze data.

When the project becomes operational at SSC, comprehensive field monitoring of acoustical (noise) levels and exhaust product characterization, air concentrations and deposition patterns will be undertaken. All data will be included in the computerized geographical information system for an environmental baseline record.

1.3 SCOPE OF THE SFEIS

The topics covered by this SFEIS are: 1) a description of the Section 404 wetlands and Section 401 water quality permitting processes this document is designed to support; 2) impacts to wetlands from construction of the ASRM test facilities at SSC; 3) additional air quality modeling results that provide air concentration and ground deposition rates of HCl, aluminum oxide, and aluminum chloride from ASRM test emissions; 4) the potential for these exhaust products to adversely affect surface and groundwater, plants, soils, wildlife, and aquatic life; and 5) the potential for these exhaust products to adversely affect the health of the general public and persons working at SSC. Particular attention is paid to short-term (acute) effects of breathing hydrogen chloride gas, acid aerosols, and aluminum oxide; and long-term (chronic) effects.

2.0 THE WETLANDS AND WATER QUALITY PERMIT PROCESSES

2.1 INTRODUCTION

Additional information relevant to ASRM program impacts on wetlands has been produced since publication of the FEIS. This information includes: 1) publication in 1989 of the Federal Wetland Delineation Manual (FIC 1989); 2) an April 1989 EPA delineation of wetlands on the proposed ASRM test site; 3) refinement of the site facility layout, road alignments, and test stand and deflection ramp preliminary layouts; and 4) additional air quality modeling that predicts both the concentration in the air and deposition on the ground of emissions resulting from ASRM testing. The information presented in this SFEIS is particularly relevant to two of the environmental permits for which NASA has applied: the Section 404 wetlands permit and the Section 401 water quality certification. The 404 wetlands permit derives its name from Section 404 of the Clean Water Act (33 USC 1344) which prohibits the discharge of dredged or fill material into waters of the United States without a permit from the ACOE. Similarly, the 401 water quality certification derives its name from Section 401 of the Clean Water Act (33 USC 1341) which requires each state to adopt and administer water quality standards through the certification process. This section describes the process and requirements of these permitting actions, and provides the background on how and why additional wetlands information was developed.

2.2 THE 404 AND 401 PERMIT PROCESSES

Beginning in July 1977, the ACOE assumed regulatory responsibility for all isolated wetlands (wetlands not directly associated with navigable waters) in the United States. This jurisdiction extends to the regulation of all proposed activities involving deposition of dredged or fill material into waters of the United States. All such activities must receive prior approval through the Section 404 permit process.

In responding to President Bush's national goal of "no overall net loss" of wetland functions, the ACOE and EPA reached a formal agreement (referred to as a Memorandum of Agreement or MOA) on how mitigative requirements would be determined for individual 404 permits (ACOE 1989). This agreement prescribes a mitigative process beginning with avoiding impacts, then minimizing impacts, and finally compensatory mitigation. An exception to this sequential process involves areas with a high proportion of wetland. In these cases, it is stated that completely avoiding impacts may not be possible; the goal may be to minimize impacts and/or compensate for wetland loss. In keeping with the tenor of the agreement, NASA has attempted to avoid or minimize impacts to the extent possible and intends to compensate for any unavoidable loss of wetland functions (see Section 3.3).

In addition to the ACOE permitting requirements, a water quality certification is required from the state of Mississippi for all wetland-fill projects. This certification, a Section 401

permit, addresses impacts of proposed fill activities on water quality. The Federal Water Pollution Control Act, as amended by the Clean Water Act of 1977 and reauthorized in 1987, requires each state to adopt water quality standards which are administered through the Section 401 certification. State compliance with the Clean Water Act has been delegated to the Mississippi Department of Environmental Quality, Bureau of Pollution Control (MBPC) by the EPA.

All projects requiring 404 permits also require 401 certifications. If the 401 certification is denied by the Mississippi Bureau of Pollution Control, the 404 permit is automatically denied. However, approval of a 401 certification for a project does not guarantee approval of the 404 permit. Both permit processes involve a public comment period. For the ASRM project, in addition to the public comment period (30 days for the 404 permit), a single public hearing will be held for the 401 certification process. This hearing will provide additional public input for the Mississippi Bureau of Pollution Control.

For the 404 permit application, the ACOE requires a detailed description and explanation of the purpose of the project; the locations, affected areas, and types of wetlands that will be filled, including results of wetland delineations; the wetland functional values that will be affected; and a detailed description of the amount and type of fill material required. A specific project mitigative plan will be developed as part of the 404 permitting process, and NASA will be responsible for the plan's implementation.

The 401 certification does not require a separate application. The State of Mississippi will make its 401 determination based on its review of NASA's 404 permit application and supporting documents such as this SFEIS.

2.3 ADDITIONAL INFORMATION

In January 1989, a cooperative effort between four federal agencies responsible for conserving the nation's wetland resources resulted in an agreement on a technical basis for identifying and delineating wetlands. A Memorandum of Agreement between the ACOE and EPA, concerning the agencies' agreement to use the new manual when conducting a determination of wetlands, became official in March 1989. The Federal Manual for Identifying and Delineating Jurisdictional Wetlands (FIC 1989) includes specific instructions for delineating wetlands based on the presence of adequate hydrology, wetland vegetation, and wetland soils. Typically, all three criteria must be satisfied for a site to be classified as wetland under this method. Prior to the introduction of this methodology, confusion frequently arose over what constitutes a wetland because of the different types of wetlands and the agencies' differing methodologies for wetland identification and delineation.

Under the new guidelines, the hydrology requirement is assumed to be satisfied if an area has typical wetland vegetation growing on wetland soil with no evidence of man-made drainage facilities (such as ditches). The practical aspect of this new approach is a change in the way that seasonal wetlands (e.g., bottomland hardwood forests) are identified for regulatory purposes. Even though such areas do not always contain water throughout the

year, seasonal wetlands are especially important for maintaining wildlife, including many threatened and endangered species. The relevance of these guidelines to the ASRM project is that many areas in the Gulf Coastal Plain of Mississippi that may not be classified as wetlands under previous delineation methods are classified as wetlands under this new method.

The proposed ASRM test site is underlain primarily by hydric (wetland) soils. Despite the extensive ditch systems existing throughout the proposed ASRM test site, soils are saturated for much of the year. Also, despite many decades of vegetation conversion to pine plantation as a result of silvicultural (timber growing) practices, wetland vegetation (bottomland hardwood species) is still an abundant element in pine forest understories and in forest openings (pitcher plant bogs). In light of these facts and under the new federal guidelines, much of the proposed test site is classified as wetland.

In February 1989, NASA requested that the Vicksburg District ACOE determine the presence of wetlands on the proposed test site (McCaleb 1989). In March 1989 (in compliance with the two agencies' coordination agreement), the ACOE requested that the EPA conduct an investigation of the proposed ASRM test site to determine the size and extent of existing wetlands using the new federal wetland delineation method (McGregor 1989a). EPA made an April site visit with the ACOE and field-checked the presence of hydric and upland soils as indicated by the soil survey for Hancock County (USDA 1981). EPA also made visual inspections of the area to check on the presence of wetland vegetation and hydrology. On the basis of these activities, EPA determined that wetlands exist on the site, and that the soil survey for the county was a good approximate indicator of the locations of uplands and wetlands at this site. EPA's report to the ACOE indicated that all hydric soils shown on the soil survey supported wetlands, and that all nonhydric soils did not support wetlands. As a result, the majority of the proposed test site was delineated as wetland. The ACOE subsequently informed NASA that a 404 permit would be required for all wetland-filling activities associated with the ASRM project (McGregor 1989b).

Between January and May of 1990, NASA and its contractor refined the site facility layout, test stand and deflection ramp preliminary designs, and road alignments. These refinements helped in determining construction impacts to wetlands, and provided the basis for developing a general wetland mitigative plan. The results of this process are presented in Section 3.0, Primary Impacts to Wetlands From ASRM Facility Construction. In July 1990, final deflection ramp configuration and dimensions were established.

Other information relevant to ASRM program impacts on wetlands includes air quality modeling of ASRM test emissions and impact evaluations based on the additional modeling done for the PSD air emissions permit application submitted to the Mississippi Bureau of Pollution Control in August 1989 and this SFEIS in conjunction with the FEIS modeling. Results of these analyses are presented in Section 4.0, Secondary Impacts to Wetlands from ASRM Test Emissions.

3.0 PRIMARY IMPACTS TO WETLANDS FROM ASRM FACILITY CONSTRUCTION

3.1 INTRODUCTION

As noted in Section 2.0, the ACOE and EPA have adopted a mitigative process that stresses avoiding impacts, minimizing impacts, and compensating for unavoidable impacts. NASA has followed this procedure, using an iterative process that is still underway. NASA identified a general site location, selected highly functional wetland areas (such as Lion Branch) to be avoided, and considered facility layouts that met these criteria. Then more detailed wetland evaluations were undertaken and the facility layout was simultaneously refined, so that NASA could be certain that construction would avoid wetland areas such as Lion Branch and minimize wetland impacts overall. Because wetlands are so abundant on the site, no practicable alternative to construction within wetlands could be identified. The final site layout reflects the minimum possible physical and functional impact to wetlands at SSC (NASA 1990d).

3.2 WETLAND IMPACT EVALUATION

3.2.1 Wetland Delineation

As noted in Section 2.3, the EPA wetland report to the ACOE stated that all hydric soils shown on the county soil survey indicate wetlands at the proposed ASRM site, and that all nonhydric soils indicate nonwetlands (uplands). Figure 3-1 illustrates the approximate location and extent of uplands and surrounding wetlands on the proposed test site and the proposed location of project facilities. Because of the large amount of proposed wetlands in the project vicinity, uplands rather than wetlands are locally scarce.

3.2.2 Affected Wetland Types

Four major plant community types have been identified on the proposed ASRM site: 1) pine forest; 2) bottomland hardwood forest; 3) pitcher plant bogs; and 4) grasslands (Esher and Bradshaw 1988). Vegetation in the buffer zone is primarily pine forest and bottomland hardwood forest. Pitcher plant bogs, bottomland hardwood forests, and much of the pine forests can be classified as wetland. Wetland types that will be affected by construction of ASRM facilities include pine forest (Plates 3-1 and 3-2) and bottomland hardwood forests (Plate 3-3). Major concentrations of pitcher plants (Plate 3-4) will be identified and avoided during construction. The unique status of pitcher plant bogs and their diminishing numbers in the Mississippi Coastal Plain is largely a result of commercial pine plantation forestry, and NASA is committed to preserving pitcher plant bog communities. Not all pitcher plants can be avoided, however, because individual plants are scattered throughout the proposed ASRM test site.

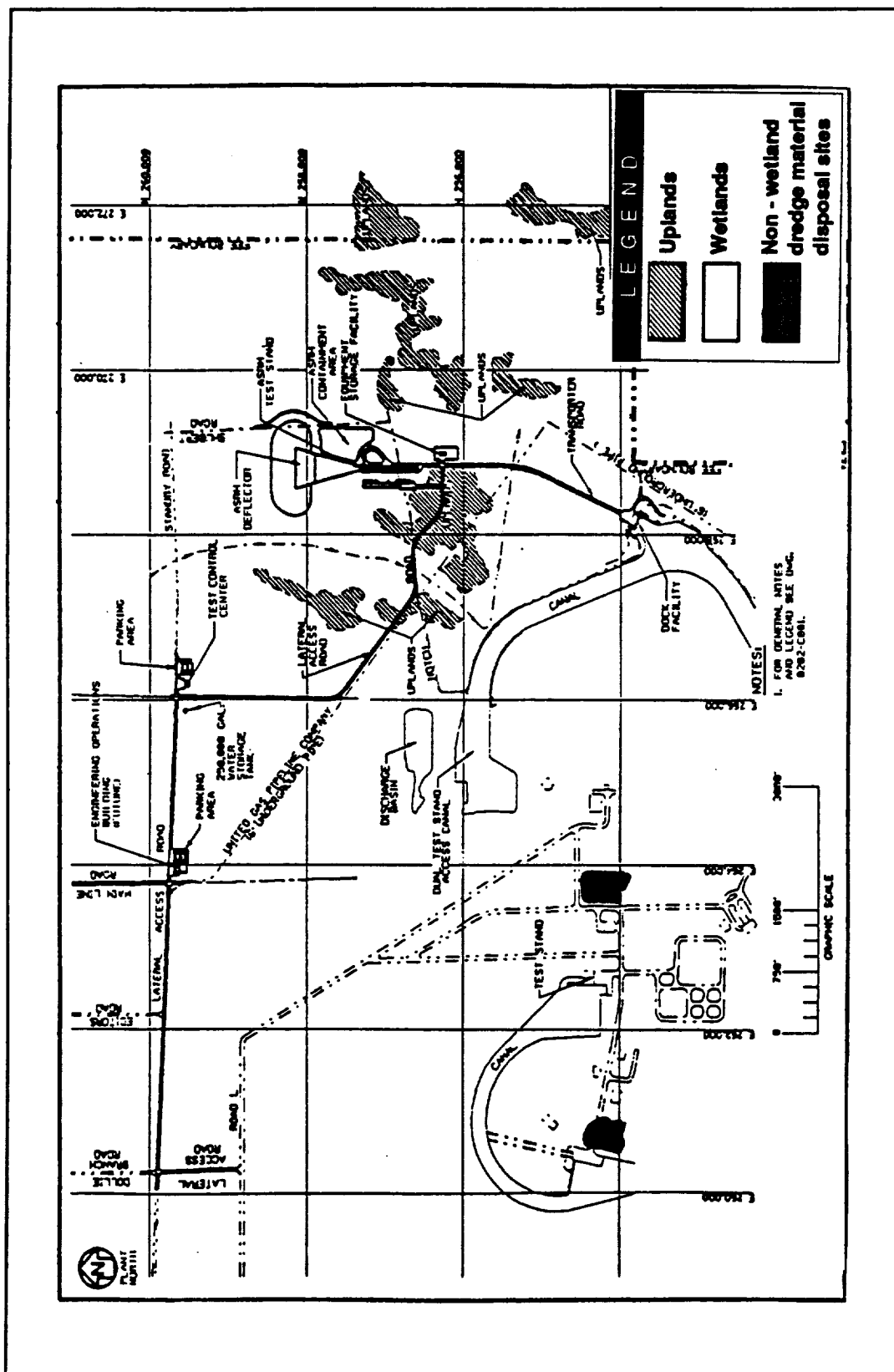


Figure 3 - 1. Uplands and wetlands surrounding the ASRM test facilities.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH



Plates 3-1 and 3-2. Typical pine forest at the SSC ASRM site.



Plate 3-3. Typical bottomland hardwood forest type.



Plate 3-4. Pitcher plant bog community (not affected by ASRM facilities).

The proposed test site also contains areas that are now considered wetlands that have formed on 1960s-era dredge spoil deposits. These areas will be identified, delineated, and avoided as sites for debris and soil dumping during construction of the ASRM facility. All spoil or excavated materials, approximately 60,000 cubic yards, will be placed in approved uplands disposal areas (see Figure 3-1). Adequate uplands area exist within these spoil deposits to accept additional quantities of fill without affecting these wetlands (Clarke 1990).

3.2.3 Affected Wetland Functional Values

Wetlands can perform important hydrological, biological, economic and social functions. The Mississippi Bureau of Pollution Control specifically recognizes six hydrological functions (MBPC 1990b), including:

- groundwater recharge and discharge
- floodflow alteration
- sediment stabilization
- sediment and toxicant retention
- nutrient removal/transformation
- production export

Additionally, wetlands can provide fish and wildlife habitat, education, recreation, and open space.

The quality of a wetland can be evaluated in terms of the quality and importance of its functions but may not be related to its size. As a result, mitigation required for wetland loss is based on functional loss rather than area loss.

Preliminary functional value analysis of both pine forest and bottomland hardwood wetland types has been completed as part of a wetland mitigation report for the ASRM project at SSC (NASA 1990d). The wetland mitigation report was submitted to the ACOE as part of NASA's Section 404 application, and extensive excerpts are included in Appendix A of this SFEIS. The wetland mitigation report concluded that the principal values of the wetlands affected (filled) by ASRM facilities are biotic and hydrologic in character. The primary biological function of the pine forest is as wildlife habitat. However, forest management has converted what appears to have been a hardwood or hardwood-pine habitat into a commercial pine plantation forest. An additional habitat function found in the pine flatwood forest is the support of pitcher plant bogs. These bogs are unique habitats that have also been adversely affected by forest management (ditching and planting of pine). Similarly, the planting of pine in swales has degraded the bottomland hardwood habitat. Pine plantation management has impaired the wildlife function by reducing hardwood (or mixed hardwood-pine) forests.

The principal hydrologic functional values of wetlands affected (filled) at the proposed ASRM test site are flood storage and desynchronization of rainfall runoff. These values, too, have been reduced by the extensive drainage ditch systems in the test area.

The Waterways Experiment Station (WES) in Vicksburg, Mississippi, will conduct additional analyses of the specific wetlands functions (known specifically as the Bottomland Hardwood Wetland Evaluation Technique, or BLH-WET) at the proposed ASRM test site (McGregor 1990). This technique is a more detailed approach for assessing wetland function and provides an estimate of the value of the wetland. The results of the WES analysis will be used by the ACOE to assist in determining mitigative needs for the ASRM project.

3.2.4 Extent of Affected Wetlands

NASA plans to keep the proposed test area free of trees. The intent is to maintain vegetation in the test area and safety zone in a nonforested state in order to prevent forest fires and control thrown debris (Clarke 1990). In preparation for construction of the ASRM test facility, NASA has begun to remove marketable timber from the building pads, test area, safety zone, and road alignments within the project area. This timber (primarily pine) is approximately 30-40 years old and covers approximately 312 acres (Table 3-1). Some topsoil high in organic matter will also be stripped away (pending approval of the 404 permit), because these soils may ignite during test firings. Grass and shrub vegetation in the project test area will be maintained by periodic controlled burning.

Of the 312 acres to be cleared for construction of the ASRM test facility, a maximum of 69 wetland acres will require clearing and filling (NASA 1990d). Table 3-1 lists the total acreage of wetlands to be cleared and filled for each of the new buildings and new or rebuilt roads and other facilities as submitted in the 404 application to the ACOE in May 1990. Specific acres of each wetland type to be filled have not been calculated, but they will be identified prior to construction and prior to development of the wetland mitigative plan. The preliminary design of the deflection ramp, for example, indicated that 24 acres of wetlands will be filled. However, it is anticipated that final ramp design will require filling less than 2 acres. Approximately 90 percent of the affected wetland area is pine with some grassland, also referred to as pine-savannah. The remainder of affected wetland is primarily bottomland hardwood forest.

3.2.5 Cumulative Impacts to Wetlands

Various regulations under which the wetlands 404 permit is administered also explicitly require consideration of cumulative environmental impacts. Bottomland hardwood forest ecosystems of the southeastern United States have been rapidly transformed or modified over the last 40 years through conversion to agricultural crops and timberland, ditching and road building, and flood control construction (Gosselink and Lee 1989). These transformations in bottomland hardwood forest ecosystems have adversely affected

Table 3-1. Approximate wetland acreage to be cleared and filled during construction of ASRM Test Facility.

Facility	Total Wetland Acres Cleared	Approximate Number of Wetland Acres Filled
Engineering Operations Building	5	2
Test Control Center	4	2
Equipment Storage Building and Test Stand Area	25	13
Deflection Ramp	38	24
Test Range	145	0
Dock Area	6	4
Roads		
Mainline Road	35	8
Lateral Access Road	34	10
Transporter Road	16	6
Power Line Right-of-Way	<u>4</u>	<u>0</u>
TOTAL	312	69 acres

Source: NASA 1990d, as revised in June 1990.

pitcher plant bogs (Folkerts 1982). Because much of the original bottomland hardwood forest on the ASRM test site was previously converted to pine forest, this wetland type has already been lost in a regional context. A small area of this pine forest will be cleared and filled for construction of the heavy-duty transporter road. The remaining wetlands to be disturbed include only pine plantation, which have existing modified hydrology and low wildlife habitat values (NASA 1990d). The majority of the wetlands to be filled or cleared are of lower functional value than the wetlands that will be protected.

In summary, a small area of bottomland hardwood forest will be filled for construction of the heavy-duty transporter road. The wetland functional values affected will be determined when the ACOE completes its BLH-WET analysis. No significant cumulative impacts are anticipated for pitcher plant bog communities, although individual pitcher plants scattered throughout the site cannot be avoided. The ASRM project has the potential to increase the quality of existing bottomland hardwood forest and the total area extent and health of pitcher plant bogs at SSC through programs involving: 1) mitigation for wetland loss; and 2) management of vegetation after removal of the current standing crop of marketable pine in areas affected by construction activities.

3.3 MITIGATION OF WETLAND IMPACTS

Federal Executive Orders on wetland protection (E.O. 11990) and floodplain management (E.O. 11988) and regulations pursuant to those orders require that no federal project be located in a wetland/floodplain if practical alternatives exist that avoid the wetland/floodplain. The Executive Orders further require that any project to be located in such areas must include all practicable measures to minimize harm to the wetland/floodplain. As noted earlier, NASA used an iterative process to reach the point where just 312 wetland acres would be affected, and most of those acres would be pine forest with relatively low functional value. Specific steps undertaken by NASA to comply with these Executive Orders included: 1) an alternatives analysis in siting the project; 2) interagency coordination; and 3) implementation of standard construction practices. For those impacts that are not avoidable, NASA continues to work with the appropriate agencies to develop an acceptable mitigative plan.

3.3.1 Alternatives Analysis for Site Selection

Since the selection of SSC as NASA's preferred ASRM test location, the ASRM facility plans have gone through three successive site layouts to avoid and minimize impacts to wetlands. Numerous meetings with the ACOE and other agencies governing wetlands permitting, wildlife, and air/water quality provided additional information in choosing the final site.

The selected site meets the following criteria: minimizes the impact to the highly functional Lion Branch area; avoids pitcher plant bogs; does not impact any existing or known future NASA program plans; minimizes the length of the heavy-duty transporter road and its effect on wetlands, especially bottomland hardwoods; and allows for the

maximum use of existing utility corridors and road beds. Because wetlands are so abundant on the site, no practicable alternative to construction within wetlands could be identified. The final site layout reflects the minimum possible physical and functional impact to wetlands at SSC (NASA 1990d).

3.3.2 Interagency Coordination

Because this project requires the filling of wetlands, an activity regulated by the ACOE under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act, the ACOE, Vicksburg District, has been providing information and assistance in the development of the project. Numerous meetings, correspondence, and phone conversations have occurred to ensure that documentation prepared by NASA and its consultants adequately addresses regulatory concerns of the ACOE. A formal application for a Section 404 permit was submitted to ACOE in May 1990. Construction of the project facilities, except for timber harvest activities excluded by law from Section 404 review, will not begin until a Section 404 permit has been issued by the Vicksburg District, ACOE. Prior to construction, NASA's wetlands mitigative plan must be reviewed and approved by the ACOE and other interested agencies.

3.3.3 Standard Construction Practices

Clearing within wetlands will be limited to the minimum necessary to complete the project. Areas to be preserved (such as pitcher plant bogs) within construction limits will be clearly marked to avoid accidental disturbance by equipment operators. Erosion and sedimentation will be controlled through use of temporary and permanent erosion control techniques. This includes, but is not limited to, temporary and permanent sediment basins and detention ponds, temporary and permanent seeding, check dams, diversion ditches, and erosion-control matting. All fill material will be clean and not contain any hazardous materials that might be harmful to the environment. A detailed, site-specific erosion control plan will be developed for the entire project prior to construction. Specific erosion-control measures will be identified at specific locations when final grading plans with cross sections and drainage details are complete.

3.3.4 Mitigation for Unavoidable Impacts to Wetlands

All areas (wetland and upland) temporarily affected by construction of the proposed ASRM test facility will be regraded and revegetated with appropriate species. However, some wetlands—excluding pitcher plant bogs—will be permanently affected. Mitigation will be based on loss of wetland function, not on area loss, and will (in part) be based on evaluations of functional value to be performed by the Waterways Experiment Station using the BLH-WET.

Mitigation for permanent loss of wetlands in the proposed ASRM test site will involve:

- 1) restoration of hydrologic functions by filling drainage ditches in the pine flatwoods elsewhere at SSC and by building low berms across selected drainage swales, with the

intent that these areas will be left to revegetate to a natural condition; 2) restoration of bottomland hardwood forest cover for wildlife by discontinuing pine plantation management, with the intent that these areas will be left to revegetate to a natural condition; and/or 3) enhancement of existing unique wetlands (pitcher plant bogs) by controlled burning in selected areas (NASA 1990d). The amount of area required for mitigation will be determined in consultation with state and federal resource management agencies (ACOE, EPA, and USFWS) and will depend on the functional values of the wetlands filled as a result of the project. Actual mitigative activities pursued will be agreed upon by NASA and the interested resource agencies. The final mitigation plan will be a requirement of the Section 404 permit issued by the ACOE.

3.4 SURVEYS FOR STATE-LISTED THREATENED OR ENDANGERED PLANT AND ANIMAL SPECIES

There is a lack of late summer and fall surveys for state-listed threatened or endangered plant and animal species that may use or reside in the wetlands. Some of these species are candidates for federal listing or are federally listed threatened or endangered. A first and important step in dealing with potential or officially federally listed threatened or endangered species is obtaining a complete inventory of species inhabiting or using the project site.

Esher and Bradshaw (1988) conducted rare plant and animal surveys on the ASRM test site from the end of March through mid-May 1988. Because of the timing required by NASA for these surveys, plants which appear and/or flower during the summer or late fall could not be observed. Also, animals that are migratory or difficult to observe in the spring may not have been recorded. Some of these migratory animals are federally listed threatened or endangered species (Esher and Bradshaw 1988). The authors also indicated that some of the nonsurveyed plant species may be listed as Category 1 or 2 species. Category 1 species are those that are candidates for addition to the federal list of endangered or threatened plants and for which the evidence of vulnerability or threat is sufficient to consider them for the list. Category 2 species are also candidates for the federal list of endangered or threatened plants, but require further research to document their vulnerability. Two Category 2 plant species and no Category 1 species were located in spring 1988 on the proposed ASRM test site by Esher and Bradshaw (1988). No animals on the federal threatened or endangered list were found.

The Federal Endangered Species Act, Section 7, defines interagency consultation procedures and protection requirements that apply to federally listed threatened or endangered species. These procedures do not apply to candidate species, even on federally sponsored projects (Thornhill 1990). However, because there may be changes of status for species listed as candidates, it is important to know what species occur on a project site. If a Category 1 species becomes officially federally listed, appropriate actions can be taken by the project proponents.

Because the biotic inventory for the ASRM site was performed during one season only, additional surveys will be done in other seasons. The remaining critical season is late summer and fall. NASA is in the process of conducting a late summer and fall survey for plant and animal species. Should unanticipated populations of federally listed species be identified, NASA will develop and implement appropriate mitigative plans. Close consultation will be maintained between NASA and the U.S. Fish and Wildlife Service (USFWS) (administrator of the Federal Endangered Species Act) on this subject.

4.0 SECONDARY IMPACTS TO WETLANDS FROM ASRM TEST EMISSIONS

The following sections discuss secondary impacts to air, water, aquatic species, plants, soils, and wildlife from ASRM test emissions. Section 4.1 describes the air dispersion modeling on which the analysis is based. Section 4.2 discusses predicted impacts under expected meteorological conditions and Section 4.3 analyzes the resulting impacts if an unexpected rain were to occur shortly after a test. Finally, Section 4.4 discusses cumulative impacts to the environment after 30 years of ASRM static testing at SSC.

4.1 DISPERSION MODELING

4.1.1 Introduction

Subsequent to issuance of the FEIS, additional information was obtained on the models used to predict air quality impacts in the FEIS. This information was used to prepare the Prevention of Significant Deterioration (PSD) air emission permit application to provide a comprehensive analysis of the air quality impacts to the Mississippi Bureau of Pollution Control. Specifically, this evaluation covered four areas:

- 1) **Predicted Exhaust Plume Composition.** The predicted composition of the exhaust plume discussed in the FEIS changed slightly due to refinement of the motor propellant weight and composition. After the Record of Decision on the FEIS was issued on April 17, 1989, NASA selected the Lockheed/Aerojet team as the final design contractor for the ASRM and the associated manufacturing, testing, and support facilities. The Lockheed/Aerojet team recommended some final design modifications in the motor, refined the fuel composition, and slightly increased the total fuel mass to 1.206 million pounds. The ASRM solid fuel specifications had been based on a sizing parameter of 1.200 million pounds of total fuel mass. These design modifications resulted in slight increases in the total aluminum oxide and hydrogen chloride (HCl) predicted (NASA 1990a).

Further, in the FEIS a propellant composition of 16 percent aluminum and not 19 percent, as specified in the final contract, was used in the FEIS modeling predictions. The corrected model input predicts higher amounts of aluminum oxide than that presented in the FEIS. NASA has now acquired all models used to evaluate ASRM exhaust. The corrected model input, which has been closely scrutinized by NASA, the Mississippi Bureau of Pollution Control, and EPA Region 4, was used to produce the modeling results presented in the PSD application and this SFEIS.

In addition, all chlorine species predicted by the plume composition model, such as hydrogen chloride, monatomic chlorine, and diatomic chlorine, were totaled and collectively modeled as hydrogen chloride in the PSD application and this SFEIS. This conservative approach therefore results in an increase in the total effective amount of hydrogen chloride used to predict impacts.

- 2) **Modeling of the Exhaust Cloud.** Since publication of the FEIS, documentation of the plume dispersion predictions used in the Space Shuttle Redesigned Solid Rocket Motor static test program in Utah became available. The prediction or modeling method used in this 1989 action was recommended by EPA Region 8 and reviewed and accepted by the state of Utah. This permit action set the first regulatory precedent for predicting dispersion of exhaust products from solid rocket motors similar to the size and performance characteristics of the ASRM. The prediction method was a combination of the model used in the ASRM FEIS (to predict exhaust product composition and quantities and plume rise stabilization altitude and dimensions) followed by a "puff" model to predict dispersion of the exhaust products. The revised prediction method was used to prepare the air emissions permit application submitted to the Mississippi Bureau of Pollution Control.
- 3) **Possible Wet and Dry Deposition of Exhaust Compounds.** Small amounts of particulate matter from the plume will be deposited at points directly downwind of the test stand. Additionally, the impacts due to the deposition of exhaust products (mainly HCl) in rain have also been addressed.
- 4) **Cumulative Impacts of Four ASRM Tests a Year Over 30 Years.** The potential for cumulative impacts due to 30 years of particulate deposition and the contribution of HCl to the atmosphere have been addressed. The cumulative impact analyses assume four tests a year for 30 years or 120 tests, although NASA's plans are to conduct only 64 tests (8 tests in the first two years and two tests a year thereafter).

The first two areas of evaluation, related to changes in the models and modeling approach, are discussed below. The results relevant to deposition of exhaust products and cumulative effects are presented in subsequent sections.

All analysis performed for the SFEIS focused on the fate of aluminum oxide particles and HCl gas (including all chlorine species with the potential to become HCl through chemical reactions in the plume), because these compounds make up the particulates and toxic gas, respectively, requiring operational and environmental management. Aluminum chlorides were also evaluated although they will be produced in very small quantities. Other compounds emitted in large quantities, such as nitrogen oxide and carbon monoxide, were analyzed earlier and are discussed in the PSD permit application submitted to the Mississippi Bureau of Pollution Control (NASA 1989b). These compounds in the projected quantities and concentrations associated with ASRM testing are not a health or environmental concern and have not undergone further analysis.

4.1.2 SFEIS Modeling Approach

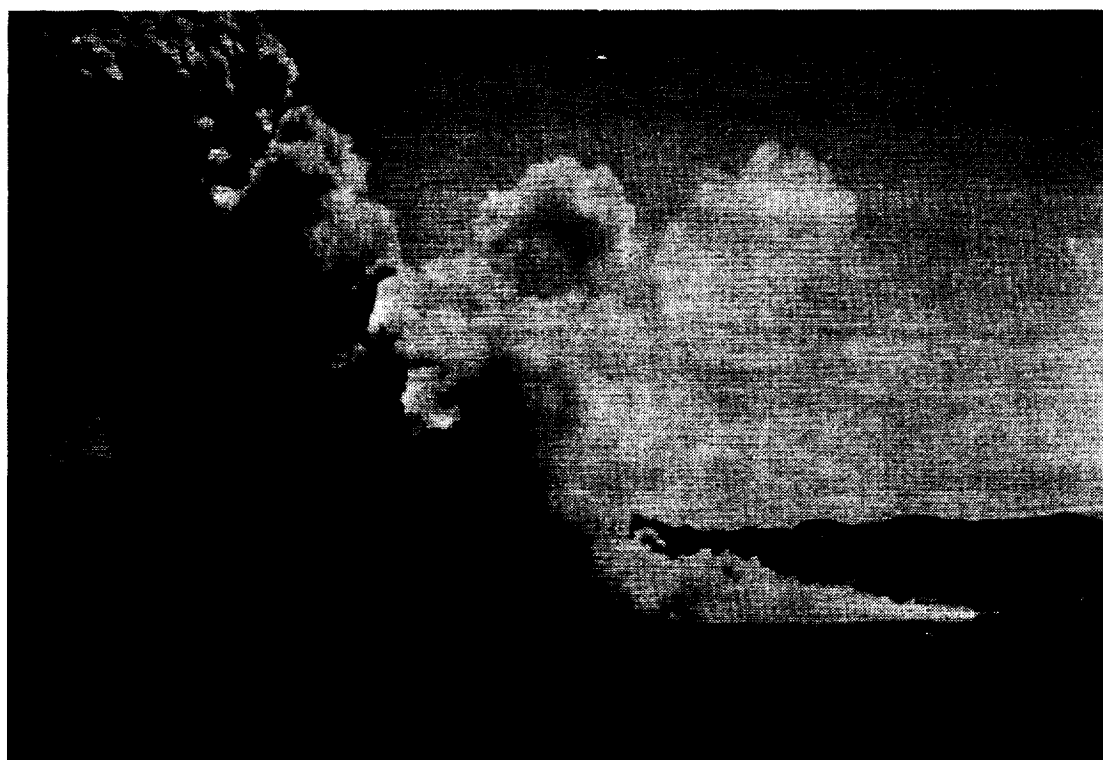
The impacts to air, soil, water, aquatic life, and wildlife from the ASRM test emissions have been predicted using sophisticated modeling of ASRM fuel combustion, exhaust plume rise, and atmospheric dispersion. As discussed earlier, the modeling procedure used in this SFEIS is the same as the one used for preparation of the PSD permit application (NASA 1989b).

DESCRIPTION OF SRM TESTING

The SRM tests at the Thiokol test complex in Utah have been closely observed and monitored since 1988. The information gathered during these tests has been used to develop a modeling approach which closely simulates an actual SRM test under a variety of meteorological conditions and climates. The following description of an SRM test was drawn from observations from helicopters, Lear jets, and the ground; exhaust plume sampling in the path of the plume both on the ground and aloft; and satellite data.

A typical SRM test proceeds in three stages: 1) ignition and firing of fuel; 2) buoyant rise of the plume to its final elevation; and 3) movement and dispersion of the elevated plume and transport downwind. The initial stage begins with the motor secured in a horizontal position. After ignition, the solid fuel begins to burn at a temperature of 6,000°F and continues to burn for about two minutes until all of the fuel has been used. During the firing of the fuel, the superheated exhaust is thrust from the nozzle at approximately 5,500 mph. At the Utah test site, the exhaust moved horizontally until it impacted a hill behind the test stand, at which point the exhaust slowed considerably (to about 700 mph). When the exhaust encountered the barrier, it was redirected upward (Plates 4-1 and 4-2). At SSC, a deflection ramp is proposed for the ASRM testing that will function in a similar way (see Section 4.2.1, Control Technologies/Mitigation Alternatives). After being deflected upward, the exhaust quickly loses its initial momentum and continues to rise due to the heat or thermal buoyancy. By the time all of the fuel has burned (about 2 minutes later), part of the plume has risen to several thousand feet in the atmosphere while the bottom of the plume is still on the ground.

The second stage of the test consists of the buoyant plume continually rising to its final elevation. When the plume rises to these higher altitudes, it cools due to the lower atmospheric pressure and mixes with the ambient air, which further cools the plume. This process of rising, mixing, and cooling continues until the plume temperature equals the ambient air temperature. The final elevation at which the temperatures are equal is called the plume stabilization height or final elevation. Virtually all the exhaust that is emitted throughout the two-minute burn rises in this way, raising the plume base many thousand feet above the ground.



Plates 4-1 and 4-2. SRM static tests at Thiokol Test Complex, Utah. Photographs show the growth of the exhaust plume during the first stage of a static test.

In the third stage of the test, the plume is blown by the upper-level winds and is dispersed in the upper atmosphere. When the plume has reached its final elevation and begins moving with the upper-level winds, it has vertical and lateral dimensions of several miles. In this stage, turbulence breaks up the plume and mixes it with the ambient air. By the time the plume has been blown a few miles downwind, it has spread out and broken up to such an extent that it is no longer visible.

MODELING PROTOCOL

The ASRM test is not like an industrial smoke stack or other stationary sources. Models that are used for these types of emissions would not be appropriate for the ASRM test. However, the three-stage test scenario can be simulated by combining several different models into one integrated procedure. The relationships between the various models are presented schematically in Figure 4-1. In the first stage of a test, the fuel is burned at 6,000°F producing the thrust and exhaust. The temperature of the exhaust and its chemical composition have been modeled using one part (the plume composition subprogram) of a larger program called Products of Combustion/Atmospheric Dispersion (PCAD).

The second stage of the test involves the plume's buoyant rise and initial expansion. These processes have been modeled using another part (the plume elevation subprogram) of PCAD. Finally, the transport and dispersion of the elevated plume have been modeled using a puff-dispersion model, INPUFF 2.3, capable of simulating the dispersion of an isolated plume at high altitudes.

PCAD MODELING

The PCAD model was developed specifically for predicting exhaust plume composition, final plume elevation (stabilization height), and initial plume dimensions. The PCAD model performs these tasks in two separate subprograms.

The exhaust plume composition subprogram is a modified version of a program written at the NASA Lewis Research Center to calculate chemical compositions of exhaust formed during a solid rocket motor firing (Gordon and McBride 1976). This subprogram uses engineering design inputs for the ASRM (i.e., chemical composition of the fuel, chemical and physical data of the fuel compounds, mass of the fuel, and duration of the firing) to compute the quantities of each chemical produced and the initial temperature of the plume (Figure 4-2).

The plume elevation subprogram computes the altitude of the center of the plume when it has stabilized and will no longer rise, and the initial dimensions of the plume at its final altitude. The final plume elevation is calculated by using the Briggs plume rise equation (Briggs 1975) as modified by the U.S. Army and described in a report on chemical hazard prediction (Whitacre and Myirski 1984). The plume elevation subprogram uses the output from the plume composition subprogram (plume temperature and heat release rate) together with meteorological data (wind speed, ambient air temperature, vertical temperature profile

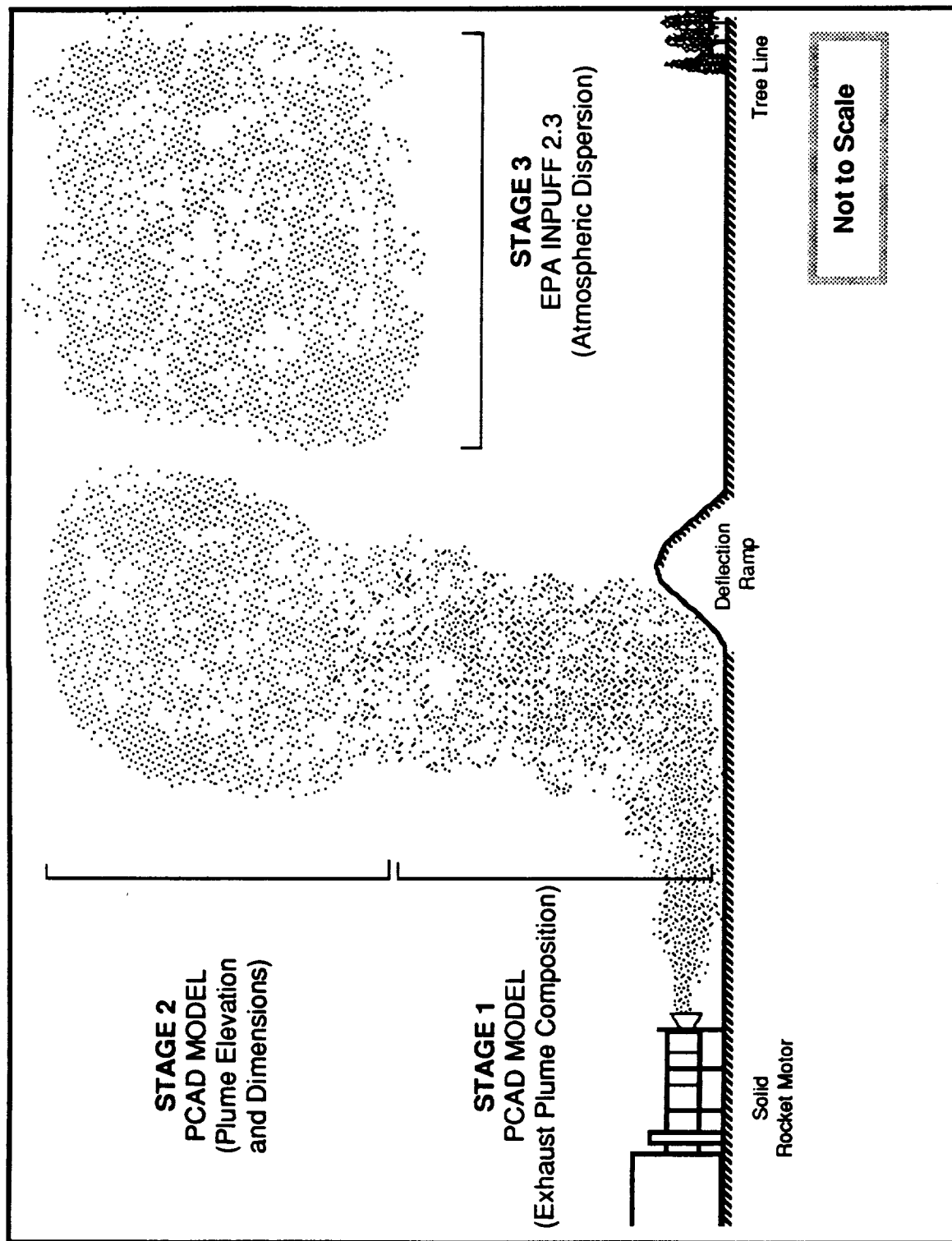


Figure 4-1. ASRM Test Stages and Modeling Protocol.

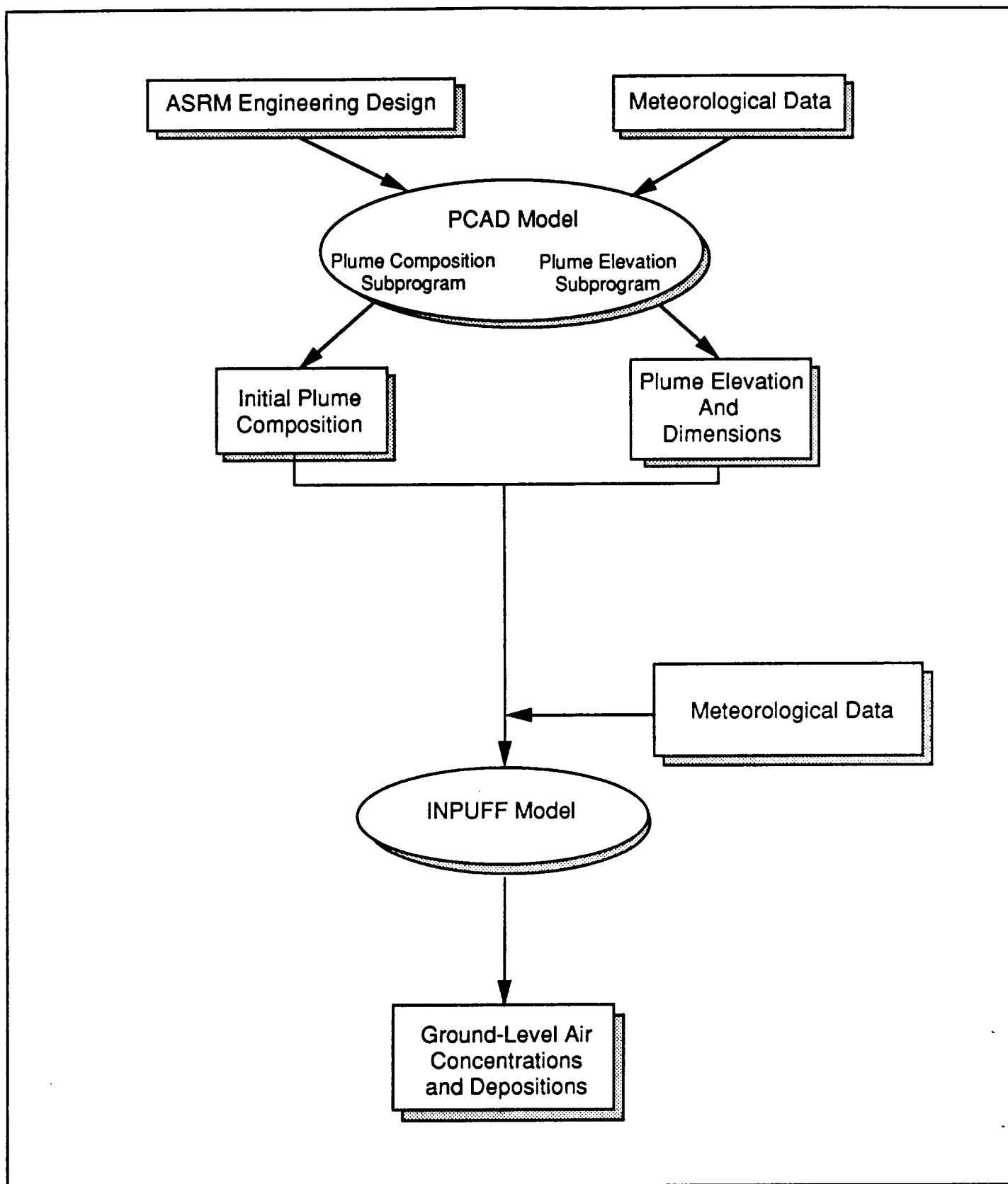


Figure 4-2. Flow chart for modeling of ASRM Exhaust Plume Composition and Dispersion

of the atmosphere, and air density which is a function of air pressure and moisture in the air) to compute the final elevation of the center of the plume (Figure 4-2).

The final and overall vertical dimension (radius) of the plume is estimated as approximately 75 percent of the centerline stabilization altitude. Since ground-level concentrations of plume components depend upon the ability of the atmosphere to mix the plume with ground-level air, the larger the radius or vertical dimension of the plume, the higher the ground-level concentrations. Use of a large, initial plume dimension is therefore considered a conservative estimate; that is, a large initial plume dimension may lead to overestimating ground-level concentrations.

INPUFF 2.3 MODELING

The transport and dispersion model, INPUFF 2.3, uses as input the plume composition, final plume altitude, and plume dimensions predicted by PCAD, together with meteorological data typical of the SSC vicinity (Figure 4-2). INPUFF 2.3 is a Gaussian dispersion puff model that is capable of characterizing the transport and dispersion of an instantaneously released puff of gases and particles. INPUFF 2.3 simulates the dispersion of an isolated puff as it moves horizontally with the wind. The mathematical equation used by INPUFF 2.3 to compute the concentration distribution in the plume simulates average turbulent mixing in the atmosphere. Since it is not possible to predict the exact concentration distribution for a single puff plume, computation of the average concentration distribution is the best approach (Hanna et al. 1982).

A concentration distribution used in the INPUFF 2.3 model assumes that part of the plume will immediately reach the ground after it has risen to its final altitude. Observations of solid rocket motor tests, however, indicate that none of the exhaust plume reaches the ground in the immediate vicinity (1 mile) of the test site (El Dorado 1990). Given this actual test information, it appears likely that the model used in the ASRM test analysis overpredicts the ground-level concentrations, especially close to the test site. Use of the model therefore gives conservative estimates for this application; that is, any ground-level concentrations predicted by the model are likely to be higher than the concentrations that would actually occur.^{1/} The INPUFF 2.3 model generates two-minute average ground-level concentrations for specified distances downwind of the test stand continuously for 24 hours. These successive two-minute average concentrations may then be used to find the maximum instantaneous, maximum 1-hour, and maximum 24-hour concentrations. Additionally, these concentrations may be used to compute the total deposition of particulate matter at a particular point.

^{1/} Modeling used for the FEIS was similar to the modeling just described, except that the FEIS modeling used the PCAD dispersion subprogram in place of the INPUFF 2.3 dispersion model. The PCAD dispersion subprogram utilizes a continuous point source plume model as opposed to a puff dispersion model. The FEIS modeling approach is also considered a conservative approach, and demonstrated that the ground-level concentrations of all constituents would be below the applicable air quality standards.

4.1.3 Modeling Inputs and Results

PCAD MODELING

The engineering design inputs for the PCAD plume composition subprogram included 1.206 million pounds of solid fuel to be burned in 2.25 minutes among other inputs (El Dorado 1989). PCAD predicts that each test will generate approximately 216 tons of particulate matter, mainly aluminum oxide, and 127 tons of HCl and other chlorine forms in addition to water vapor, oxygen, nitrogen, carbon dioxide, and trace amounts of other combustion products. These compounds will be emitted from the nozzle at a temperature of 6,000°F. The exhaust will quickly cool to about 2,500°F at 800 feet down the plume centerline from the nozzle.

After the exhaust plume has lost its initial horizontal momentum, it will have enough heat to buoyantly rise about 13,000 feet (final centerline altitude), and will expand into a spherical cloud approximately 10,000 feet in radius (Table 4-1). These predictions are consistent with actual observations and measurements of solid rocket motor tests (El Dorado 1990).

INPUFF 2.3 MODELING

The INPUFF 2.3 modeling utilized the PCAD output (Table 4-1) together with meteorological data typical of the SSC vicinity (Table 4-2) to compute the ground-level concentrations at various distances from the test stand. The INPUFF 2.3 modeling was conducted in accordance with the modeling methodology in the PSD permit application. Although PCAD predicts only 103 tons of HCl will be produced, all of the chlorine produced was assumed to react in the plume to form HCl. The dispersion of the HCl, therefore, was assumed to consist of all chlorine ions (24 tons) as well as the HCl (103 tons), creating a total mass of 127 tons of HCl. The results of the INPUFF 2.3 modeling are presented in detail in Section 4.2.1.

4.1.4 Cases Considered in this SFEIS

In the FEIS, the consequences of solid rocket motor testing were evaluated under "expected" conditions, with testing designed to take place only in favorable weather conditions and when no rain was included in the short-term weather forecast. These are the test conditions that prevent most impacts on the environment. While NASA has confidence in the weather forecasting personnel and sophisticated equipment that will be used for the ASRM project, it is reasonable to look at potential impacts from testing under "unexpected" weather conditions.

Since the release of the FEIS, additional modeling has been performed to characterize potential impacts from ASRM testing under a range of conditions. Two scenarios are included in this SFEIS and may generally be classified as "Expected" (Case 1), and "Unexpected" (Case 2). The primary reason for looking at two cases is to evaluate the impacts when it does not rain for at least a few hours after a test (the expected condition,

Table 4-1. PCAD Model results.

Parameter	Value
Total Fuel Mass	1,206,000 lbs.
Total HCl Emitted	254,789 lbs. (127 tons) ^{a/}
Total Aluminum Oxide Emitted (particles)	432,885 lbs. (216 tons)
Total Aluminum Chlorides Emitted	61.5 lbs (0.03 tons) ^{b/}
Final Plume Rise (centerline altitude)	13,380 feet ^{c/}
Plume Dimensions (diameter)	10,038 feet ^{c/}

a/ This figure includes the total HCl and all other chlorine species produced (NASA 1990a).

b/ This figure includes the aluminum chloride oxide and aluminum chloride produced (NASA 1990a).

c/ Using the same meteorological input parameters shown in Table 4-2 along with air density, air pressure, and other parameters typical of sea level conditions.

Table 4-2. INPUFF Model Input parameters.

Parameter	Value
Windspeed (32-foot aerometer height)	4.5 miles per hour
Stability Class ^{a/}	C (daytime, slightly unstable)
Mixing Height ^{b/}	4,621 feet ^{c/}

a/ The Stability Class is used as a measure of the ability of the atmosphere to disperse pollutants. Stability class "A" represents a high degree of dispersion and stability class "F" represents a low degree of dispersion.

b/ The dispersion of pollutants in the lower atmosphere is greatly aided by the convective and turbulent mixing that takes place. The vertical extent to which this mixing takes place varies daily and from season to season, and is also affected by topographical features. The greater the vertical extent of the mixing layer, the larger the volume of the atmosphere available to reduce the pollutant concentration. However, for the high final plume elevations associated with the ASRM plume, a higher vertical extent of the mixing layer may increase ground-level pollutant concentrations (see Appendix B for explanation). The vertical extent of the mixing layer is called the mixing height.

c/ Average afternoon mixing height for Jackson, Mississippi (Appendix B).

Case 1) and when it does rain soon after a test (an unexpected condition, Case 2). These two cases are examined separately, because the resulting impacts are often different. As documented in the following sections, neither case produces any significant adverse impacts to human health or the environment.

CASE 1 - EXPECTED CONDITIONS

Case 1 examines the consequences of motor testing under expected test conditions. For Case 1 the exhaust plume was modeled using physical and meteorological inputs typical of coastal Mississippi (Table 4-2). These include light upper-level wind speeds, average air temperatures and mixing conditions for daytime hours, and no defined wind directions. The modeled parameters are within the range discussed in NASA's PSD permit application (NASA 1989b). As part of the PSD permitting process, the Mississippi Bureau of Pollution Control will define the precise range of weather conditions under which testing will be allowed.

Case 1 is based on controls designed to ensure that it does not rain in the vicinity of SSC until the plume has dissipated. NASA originally stated that testing will proceed only when no rainfall has been forecast for two hours. A two-hour test window in connection with solid rocket motor testing was first recommended in 1967, following a solid rocket motor test conducted in Dade County, Florida. The test took place during rainfall and resulted in acid rain damage to crops (NASA 1978). To ensure that this type of impact is avoided during ASRM testing, more detailed analysis of the ASRM exhaust plume dispersion was conducted. The additional analysis indicates that a 2- to 4-hour no-rain test window, depending on wind speeds, would be a more conservative and appropriate window to ensure negligible impacts on rainfall acidity. A 2- to 4-hour, no-rain test window is well within the weather forecasting ability of the planned ASRM weather forecasting support system.

CASE 2 - UNEXPECTED CONDITIONS

Case 2 is based on the unlikely assumption that short-term weather forecasting efforts break down and that a significant rain event occurs shortly after testing. For this case, several conservative assumptions were made: 1) the rain cloud forms at the same location as the exhaust plume, 2) the exhaust plume is entirely taken into the rain cloud, and 3) the rain cloud size is typical of coastal Mississippi and enough rain falls so that all of the acid in the exhaust plume is removed by the rain and falls to the ground in raindrops. The particular scenario examined in this SFEIS includes a large rain event 1 hour after the test.

4.2 IMPACTS UNDER CASE 1 CONDITIONS

4.2.1 Air Quality

INTRODUCTION

The air quality impacts due to ASRM testing have been evaluated for the two cases described in Section 4.1.4 using the modeling methodology discussed in Section 4.1.2. The modeling results presented below indicate that air quality impacts are well below federal and state air quality standards.

MODELING RESULTS: CASE 1

The results of the INPUFF 2.3 model indicate that the exhaust plume will move as a slowly dispersing sphere at the speed of the upper-level winds. The model predicts that the plume will rapidly mix with air at the ground and that low concentrations of HCl, aluminum oxide, and aluminum chlorides will remain at ground level for short periods of time as the plume moves overhead.

Time-averaged concentrations, such as the 1-hour and 24-hour averages, may be calculated for various distances from the test stand (Table 4-3). Table 4-3 presents the predicted maximum, 1-hour, and 24-hour average concentrations for HCl, aluminum oxide, and aluminum chloride at 0.6, 3, 4.2, 6, and 12 miles from the test stand.

Table 4-3 also compares the predicted ground-level concentrations to applicable federal and state regulations. The air concentration of HCl will be well below the applicable 1-hour and 24-hour standards. There are no air quality standards set specifically for aluminum oxide and aluminum chloride, because they are covered by general National Ambient Air Quality Standards (NAAQS) pertaining to all particulates. Aluminum oxide and aluminum chloride concentrations were therefore added to the background concentration of particulates already in the atmosphere to arrive at a total value to be compared to the standard. The maximum ground-level concentrations of aluminum oxide and aluminum chlorides, when added to the background level of particulates in the atmosphere, are predicted to be below the applicable regulatory standards (Table 4-3).

The values shown in Table 4-3 are those predicted by the INPUFF 2.3 model, and they represent the predicted concentration of HCl, aluminum oxide, and aluminum chloride in the air at ground level. The same model was used to estimate deposition, or the amount of material that would be deposited on the ground, on plants, in surface waters, or on other surfaces. Predicted deposition rates are very dependent on the interaction of various elements in the exhaust plume, as described below.

Table 4-3. Modeling results for ground-level air concentrations.

Compound	Averaging Time b/	Distance from Test Stand (concentration in mg/m ³)a/					Applicable Air Quality Standards (mg/m ³)
		0.6 mile	3 miles	4.2 miles d/	6 miles	12 miles	
HCl	Maximum	0.24	0.23	0.22	0.21	0.19	7.0 d/
	1 hr.	0.11	0.15	0.15	0.15	0.14	1.5 g/
	24 hr.	0.0060	0.0087	0.0088	0.0087	0.0083	0.07 y/
ASRM Particulates							
Aluminum	Maximum	0.40	0.39	0.38	0.36	0.33	none
Oxide	1 hr.	0.20	0.26	0.26	0.25	0.24	10.0 g/
	24 hr.	0.010	0.015	0.015	0.015	0.013	none
Aluminum	Maximum	0.000059	0.000057	0.000055	0.000054	0.000049	7.0 d/
Chlorides	1 hr.	0.000028	0.000038	0.000038	0.000037	0.000035	2.0 y/
	24 hr.	0.0000015	0.0000022	0.0000022	0.0000022	0.0000020	0.07 y/
Total ASRM Particulates	24 hr.	0.010	0.015	0.015	0.015	0.013	none
ASRM Particulates + Background Particulates	24 hr.	0.056	0.061	0.061	0.061	0.059	0.15 b/y/

(footnotes on following page)

Table 4-3. Modeling results for ground-level air concentrations (continued).

- a/ The 1-hour and 24-hour ground-level concentrations do not steadily decrease with distance from the test stand because of the initial size of the plume. Since the initial plume diameter has lateral dimensions of several miles, part of the plume will be over the 0.6- and 3-mile locations immediately after firing. As the wind blows the plume away from the test stand, the center of the plume quickly passes over the 0.6- and 3-mile locations and the ground-level concentrations rapidly fall to zero. Because the entire plume will pass over the 4.2-mile location, the plume will spend more time over this location than over the 0.6- and 3-mile locations; therefore, the 1- or 24-hour average concentration will be highest at the 4.2-mile location.
- b/ The averaging time is the period of time for which the average concentration is calculated. The 1-hour average is given for the 60 minutes when concentrations are greatest. Similarly, the 24-hour average is calculated for the 24 hours when concentrations are greatest.
- c/ A distance of 4.2 miles is the predicted point of maximum 24-hour concentration.
- d/ OSHA 1989. Maximum occupational exposure (ceiling) limit which should not be exceeded at anytime.
- e/ NRC 1987. Recommended Short-Term Public Emergency Guidance Levels for Community Exposures During Space Shuttle Launches.
- f/ Mississippi Bureau of Pollution Control (MBPC) Regulation APC-S-1, Section 5.2.
- g/ OSHA 1989. Eight-hour time weighted average occupational standard.
- h/ NAAQS Standard for Particulate Matter.
- i/ Standards for the PSD application apply to PM₁₀. Only Total Suspended Particulates were estimated in the SFEIS and, therefore, cannot be compared to PSD standards.

Hydrogen Chloride Gas

HCl will be emitted as a gas from the motor nozzle. Although HCl is very soluble in water, it does not deposit readily onto dry aerosols or other dry surfaces when the relative humidity is below 100 percent (Cocks and McElroy 1984). Because the atmosphere under Case 1 conditions would have a relative humidity lower than 100 percent, direct dry deposition of HCl gas onto the ground and vegetation would be insignificant.

Hydrogen Chloride Aerosols

Acid aerosols^{1/} naturally exist at coastal locations such as SSC due to the emissions of sulfurous and nitrous gases and particles from natural and man-made sources. The high relative humidity near the ground at SSC means that the acid aerosols will be aqueous aerosols.^{2/} Since HCl is soluble in aqueous aerosols, the HCl gas from a test firing would dissolve in the existing aqueous acid aerosols^{3/} and the dissolved HCl would tend to increase the acidity of the affected aerosols (NASA 1990a; Sebacher et al. 1984). When the relative humidity near the ground is high (greater than 90 percent), most of the HCl near the ground will be dissolved in aerosols (Cofer et al. 1985; Anderson 1983). The HCl concentrations in aerosols near the ground would then be equal to the ground-level HCl concentrations given in Table 4-3.

Emissions of sulfur dioxide and nitrogen dioxide from man-made sources (e.g., power plants, industrial boilers, automobiles) in southern Mississippi are primarily responsible for the background acid aerosol concentration at SSC (EPA 1988b). These existing sulfur dioxide and nitrogen dioxide concentrations are well below the regulatory standards in Mississippi (MBPC 1988), even though they produce acid aerosol concentrations that are much higher than the temporary HCl aerosol concentrations produced by an ASRM test. This can be demonstrated by comparing the 24-hour sulfur dioxide concentration as measured at Gulfport, Mississippi (45 miles east of SSC) of 0.15 mg/m³ to the maximum 24-hour HCl concentration estimated for the ASRM of 0.0088 mg/m³ (see 24-hour maximum concentration at 4.2 miles, Table 4-3). HCl from the ASRM, therefore, will constitute an insignificant fraction of an already acceptable acid aerosol concentration.

The deposition rate of HCl aerosols is very low due to their small size (Hanna et al. 1982; Reist 1984). Since the ASRM exhaust plume will pass over any one point in about two hours with exhaust product concentrations below federal and state standards which were

1/ The term aerosols refers to small (less than 100 μm) solid and liquid particles suspended in the air. The mean size of acid aerosols is 0.2 μm . Raindrops, which are near a millimeter in size or more, and rapidly fall to the ground, are not called aerosols. A micrometer (μm) is equal to a millionth of a meter. See Glossary for explanation of relative particle sizes.

2/ Aqueous aerosols are particles composed of water and dissolved compound(s) such as sulfates and nitrates.

3/ Only the aqueous aerosols in relatively high humidity near the ground would be capable of absorbing significant quantities of HCl.

set to be protective of human health and the environment, the HCl aerosol deposition onto the ground, vegetation, and other surfaces (e.g., automobiles and houses) will be insignificant. Therefore, no impacts due to deposition of acid aerosols on automobiles and houses are expected as a result of the testing.^{1/} The cumulative HCl deposition impacts from 30 years of testing and the long-range fate of the HCl are discussed in Section 4.4.

Aluminum Oxide

The ambient air concentrations of aluminum oxide were modeled similarly to the HCl concentrations (Table 4-3). For a monitor stationed 6 miles downwind from the test stand, the aluminum oxide concentration would reach a peak of 0.36 mg/m³ after about one hour. The concentration would then fall again to zero after about two hours. The 24-hour average concentration of aluminum oxide at the 6-mile monitor would be 0.015 mg/m³ (Table 4-3).

In addition to the suspended particle concentrations, some of the aluminum oxide would deposit onto the ground, plants, and other surfaces. The total deposition was calculated from the INPUFF 2.3 model results at five downwind locations assuming an average particle diameter of 2 μ m (Cofer et al. 1987). The total aluminum oxide depositions at 0.6, 3, 4.2, 6, and 12 miles from the test stand are depicted graphically in Figure 4-3. The amount of aluminum oxide deposition at a certain point downwind will depend upon the concentration in the air and length of time the exhaust plume is over that point. For example, a deposition monitor at the point of maximum deposition (4.2 miles) would measure a total aluminum oxide deposition of 1.56 mg/m² (Figure 4-3, Table 4-4).

Aluminum Chlorides in Motor Exhaust

Approximately 90 pounds of aluminum compounds other than aluminum oxide are created during the firing of a motor. These include 61.5 pounds of aluminum chlorides (AlCl₃ and AlCl₂), which represents about 0.01 percent of all aluminum compounds in the exhaust plume. The ground-level air concentrations and depositions of aluminum chlorides are given in Tables 4-3 and 4-4, respectively.

Aluminum Chloride Formation in the Plume

The formation of aluminum chlorides in the atmosphere after the plume has been emitted from the motor depends upon chemical reactions between the HCl gas, water vapor, and aluminum oxide particles. The combustion component of the PCAD model computes the quantity of aluminum chlorides produced at 6,000°F during combustion, but does not consider chemical reactions that may occur after the plume has cooled. The subsequent

^{1/} There have been a few claims of damage to automobile paint coats at KSC, Florida, over the life of the Shuttle launch program, but none has been substantiated (NASA 1990c). The launch complex is cooled by a large volume of water which causes immediate acid deposition at KSC. Cooling water will not be used at SSC.

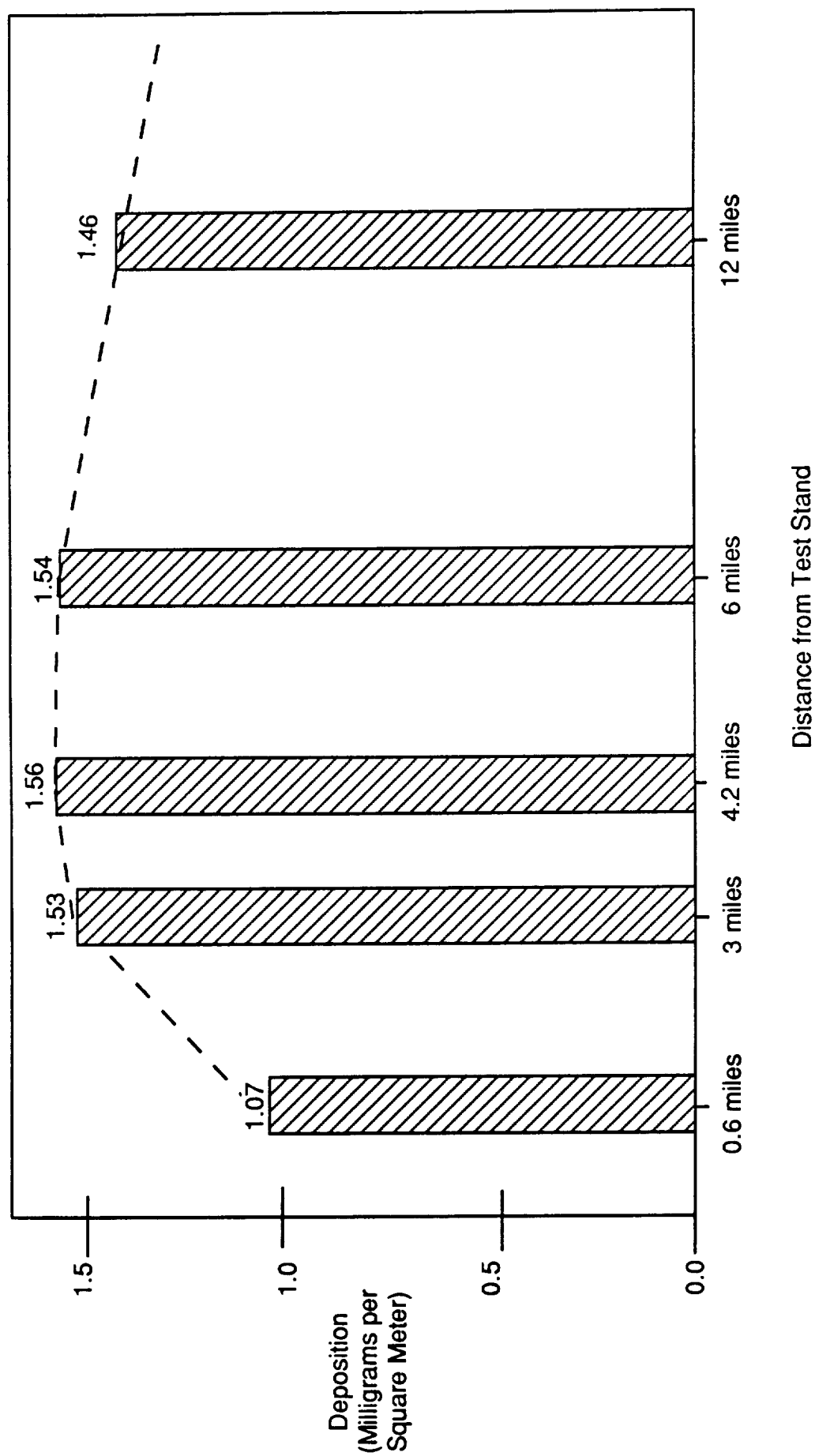


Figure 4-3. Maximum Aluminum Oxide deposition at locations downwind from the test stand for a single ASRM test.

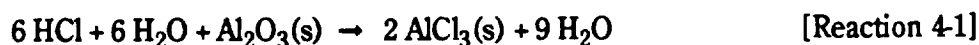
Table 4-4. Predicted depositions of aluminum oxide and aluminum chloride particles at five locations downwind from the test stand.

Compound	Distance from Test Stand (Deposition in mg/m ²)				
	0.6 mile	3 miles	4.2 miles	6 miles	12 miles
Aluminum Oxide	1.07 ^{a/}	1.53	1.56	1.54	1.46
Aluminum Chlorides	0.00016 ^{a/}	0.00022	0.00023	0.00023	0.00021

^{a/} The deposition of aluminum oxide and aluminum chlorides depends upon the air concentrations and the time the plume is over a specific location. Although plume concentrations are highest initially, the plume actually spends less time over locations at 0.6 mile and 3 miles downwind from the test stand than at 4.2, 6, or 12 miles. The resulting deposition at 0.6 mile and 3 miles, therefore, would be lower than at other locations. Although the plume spends the same amount of time over 6 miles and 12 miles, the deposition at 12 miles would be lower than at 6 miles, because the air concentrations would be lower at 12 miles than at 6 miles.

reactions in the cooling plume that may lead to the formation of aluminum chloride are considered below.^{1/}

Under expected conditions, water vapor may exist in the ambient air, the amount depending upon the absolute humidity in the air. The formation of aluminum chloride requires a reaction between an aluminum oxide particle, HCl molecules, and water molecules. Water vapor molecules (H₂O) must first react with the HCl molecules to form compounds which can then react with the aluminum oxide (Al₂O₃) to form aluminum chloride (AlCl₃). The reactions to form aluminum chloride may be combined and summarized as follows:



The probability of this reaction occurring is evaluated by considering the thermodynamics involved^{2/}, the air temperature, the air pressure, and the concentrations of the compounds. For the conditions associated with a buoyantly rising plume still near the ground, the reaction is not thermodynamically favored (CRC 1989). As the plume ascends and the pressure and temperature drop, the reaction is even less likely to occur. Thus, the compounds in the exhaust plume will not tend to form aluminum chloride after the initial combustion phase.

The presence of chlorides has been noted in chemical analyses of powders deposited on the launch facility and on the ground immediately adjacent to the launch facility at KSC following Space Shuttle launches, and similarly noted in some airborne samples of the exhaust plume (Cofer et al. 1984). Cofer interpreted these data to demonstrate the formation of aluminum chloride in the exhaust plume, but did not present a detailed mechanism for their formation or an analysis of their chemical form. As demonstrated by the PCAD modeling, however, small amounts of aluminum chloride are expected to be produced as a product of combustion, thereby explaining deposits of chlorides on the ground and launch facility. The chlorides found in the airborne samples of the Space Shuttle exhaust are also expected since the Shuttle SRMs will continue to produce chlorides as the Space Shuttle rises into the air, until all the fuel has been burned. The analysis presented in this SFEIS is therefore based on the foregoing description of aluminum chlorides formed solely by combustion, and not on the theory that they are formed in the exhaust plume.

1/ The formation of aluminum chloride oxide (AlClO) is assumed to be similar to aluminum chloride. Therefore, only aluminum chloride formation is analyzed here.

2/ The "thermodynamics" of the reaction refers to the energy required for the reaction to occur. In general, reactions that are thermodynamically favored (likely to occur) have a negative free energy of formation; that is, they do not require a supply of additional energy in order to occur. Reactions that are not favored (not likely to occur) have a positive free energy of formation. Chemicals with a positive free energy of formation will not react with each other without the supply of additional energy. For Reaction 4-1 at sea-level pressure and 80°F, the free energy of formation is positive (90 calories), indicating the reaction is not likely.

CONCLUSIONS

Air quality modeling using the PCAD and INPUFF 2.3 models indicates that HCl, aluminum oxide, and aluminum chloride produced by ASRM tests under expected conditions will occur in ground-level concentrations well below state and federal air quality standards. These standards exist to protect human health and the environment. Only small amounts of both aluminum oxide and aluminum chloride will be deposited on the ground and other surfaces. Therefore, no adverse impacts to human health or the environment are projected under expected conditions.

COMPARISON OF SFEIS RESULTS TO FEIS RESULTS

As discussed earlier, the modifications to the fuel mass and modeling from the FEIS to SFEIS result in a slightly different emissions estimate (Table 4-5).

Using these emissions estimates along with the more applicable puff dispersion model, INPUFF 2.3, for the PSD application and SFEIS modeling resulted in lower ground-level air concentrations for both HCl and aluminum oxide than predicted in the FEIS using the plume (PCAD) dispersion model alone. Since INPUFF 2.3 allows tracking of the exhaust plume from the test stand, average ground-level air concentrations may be more easily evaluated at specific points downwind of the test stand. This is important in evaluating human exposure and potential health effects (Section 5.0). The more realistic dispersion predicted by INPUFF 2.3 indicates that the total time of exposure to ASRM test emissions at any point away from the test stand would only last for a period of about two hours, based on a conservatively low ground-level wind speed of 4.5 miles per hour (2 m/s).

CONTROL TECHNOLOGIES/MITIGATION ALTERNATIVES

Various emission control systems and mitigative measures were studied to determine if they could be used to further reduce concentrations of HCl, aluminum oxide, and other exhaust products. Control technologies are used to either prevent the emission of air pollutants or reduce the quantity of air pollutants emitted. Mitigative measures reduce the potential impact of the emissions by increasing dispersion, which reduces the concentration of pollutants in the atmosphere. This section summarizes the findings of those studies.

Control Technologies

Several technologies were investigated to determine if they could be used to control emissions. These include wet and dry scrubbing, off-horizontal firing, and a deflection ramp.

Wet Scrubbing. Preliminary study of a wet scrubbing system indicates the system would require the construction of a spray chamber that would be capable of delivering approximately 10 million gallons of water in a 2- to 3-minute period (Sverdrup 1990).

Table 4-5. Combustion products of ASRM fuels.

Compound	Quantity Produced (Pounds)	
	Reported in FEIS	Reported in SFEIS and PSD Permit Application
HCl	228,386	254,789 a/
Aluminum Oxide	362,773	432,885
Aluminum Chlorides	Not reported	61.5 b/

a/ This figure includes the total HCl and other chlorine species produced.

b/ This figure includes the total aluminum chloride and aluminum chloride oxide produced.

When the rocket motor was fired, the exhaust plume would exit the motor and enter the spray chamber, where water from concentric spray rings would wash the HCl from the plume. The water containing the HCl, including mist, would be collected in concrete holding tanks for subsequent treatment.^{1/}

The plume resulting from wet scrubbing ASRM exhaust would be saturated with the water vapor and would exit the spray chamber near ambient temperatures. At ambient temperatures, the plume would not rise buoyantly in the atmosphere. Since the scrubbing and filtration process is not 100 percent efficient, the plume would still contain some HCl gas and acidic mist droplets. The HCl gas and acid mist in the nonbuoyant plume would remain close to the ground and could settle onto the soil, surface water, plants, and other objects in the vicinity. Assuming a 90 percent removal of HCl using the wet scrubbing system, the ground-level air concentrations of HCl gas in the low-level exhaust plume could be significantly higher than the concentration predicted for the proposed test without a scrubber. Since a ground-level plume would disperse very slowly, the existing scrubber technology would result in increased environmental impacts.

^{1/} This wet scrubbing system is different in concept and design from the water deluge system used at KSC during Space Shuttle launches. The water deluge system at KSC is used to cool the launch platform during the launch of the Space Shuttle. The water deluge system is not used to clean the motor exhaust. In addition, over 50 percent of the deluge water sprayed during the launch evaporates, producing water vapor which cannot be captured.

Further evaluations were made to determine if existing scrubber technology could be improved upon to serve the needs of the ASRM program. It was determined that the problem of releasing the plume in a saturated condition could be theoretically minimized by testing the motor in an enclosed system (NASA 1990a). However, the largest motor ever tested in such a facility contained 50,000 lbs of solid propellant. The ASRM motor contains 24 times the amount of solid propellant and has a mass flow ten times greater. This type of facility for the ASRM would be cost-prohibitive. More importantly, the effectiveness of this approach for reducing emissions is unknown. Additional known adverse environmental impacts of wet scrubbing include the production of vast quantities of scrub water that would have to be treated, and the production of a sludge which would have to be disposed of properly. Finally, the large size of the facility would require clearing and filling additional wetland areas. In summary, the negative impacts along with the unknown effectiveness of this technology for ASRM rule it out from further consideration. The concept of wet scrubbing would require additional intensive research and development, and the technology would have to be proven in pilot-scale testing before it could be implemented on static testing of a solid rocket motor the size of the ASRM.

Dry Scrubbing. Dry scrubbing is a control technology involving the chemical neutralization of the plume by passing it through a neutralizing filter medium, such as limestone or alumina (NASA 1990a). Subsequent particle collection in dry scrubbers is usually accomplished by electrostatic precipitation or baghouse filtration. Application of this technology to ASRM testing would be particularly difficult due to the heat content, the kinetic energy, and the size of the plume. For example, the maximum temperature which a baghouse can handle is approximately 500°F (Perry and Chilton 1973) and the maximum temperature which an electrostatic precipitator can handle is approximately 800°F (Perry and Chilton 1973). The plume temperature would be substantially higher than this (6,000°F) and, therefore, this technology is not considered feasible.

Off-Horizontal Testing. Off-horizontal testing is a concept that includes inclining the motor on an angle and directing the exhaust away from the ground. Redirecting the plume minimizes the amount of soil entrained in the plume, thereby reducing particulate emissions (NASA 1990a). However, all of the information required from the test firing could not be obtained if the solid rocket motor were tested in this position. The purpose of test firing is to evaluate the various motor controls, thrust operation, and electronic ignition equipment. If the motor were inclined or vertical, the axial thrust produced would consist of a weight component and a thrust produced from the propellant burn. As the propellant burned, the weight component would change, resulting in an incorrect thrust measurement. In addition, molten slag could burn through the nose portion where the majority of the electronic controls are located, and possibly destroy mechanisms which require inspection to verify performance once the test firing is complete. Off-horizontal firing is therefore not applicable to ASRM testing, since it would not meet the objectives of the test firing program.

Deflection Ramp. As noted earlier in this section, the extreme heat of the rocket motor exhaust will cause the plume to rise rapidly. A deflection ramp located behind the motor will act essentially as a firewall, redirecting the kinetic energy of the plume from horizontal (along the ground) to vertical (into the air). The deflection ramp may not affect the final height to which the plume rises since the final height depends on the thermally buoyant rise of the plume to the point at which the plume temperature equals the surrounding air temperature. However, the ramp will substantially decrease the quantity of soil entrained in the plume, and it will increase the rate of plume dispersion. Because the deflection ramp will result in reduced environmental impacts and is technologically feasible, use of a deflection ramp was selected by NASA as the best available control technology. A conceptual description of the ramp was included in the FEIS. The ramp design is the responsibility of the Lockheed/Aerojet team (NASA 1990a). The final configuration and dimensions indicate a ramp approximately 360 feet long and varying in width from 80 feet at the end of the test stand to 200 feet at the furthest point from the test stand. The first 250 feet of the ramp will be flat. The ramp will then curve upward to a height of 60 feet above the flat portion of the ramp. The ramp will have a concrete surface and will be surrounded by a berm about 10 feet wide and a ditch about 10 feet wide. Water runoff from the test stand and ramp will be controlled and directed to a discharge pond. Discharge of this runoff will require a modification of SSC's NPDES permit from the Mississippi Bureau of Pollution Control. This permit modification was applied for in June 1990.

Mitigative Measures

In addition to air pollution control technologies, measures which could theoretically be used to mitigate impacts of the air emissions on land were also evaluated. These measures include off-shore testing and testing only during a prescribed "weather envelope."

Off-Shore Testing. An off-shore test platform was evaluated as a way to limit the exposure of terrestrial flora and fauna. Off-shore testing has several serious technical drawbacks, including the need for a separate platform for the test control center and personnel, and the logistical concerns associated with delivering and servicing the rocket motors at sea. The most serious technical drawback to off-shore testing is the need for an absolutely rigid test stand. Thrust matching between the two Shuttle boosters is a very critical performance parameter in ensuring vehicle control during ascent. Although an off-shore structural system could be stabilized to handle a 3.5 million pound thrust, the structural system could not economically be made with the required rigidity to avoid compromising the accuracy and precision of the thrust measurement data. This approach is therefore not considered feasible for the ASRM testing, because it could not meet the objectives of the test firing program.

Weather Envelope. The dispersion models indicate that the concentration of emissions from the test are greatly influenced by the meteorological conditions that exist during the firing period. In fact, it is possible to substantially reduce potential environmental impacts by performing the ASRM tests under specific meteorological conditions. These specific meteorological conditions define a weather envelope which would reduce the ground-level

air concentrations of exhaust products, reduce the dry deposition of aluminum oxide and aluminum chlorides, and prevent the deposition of HCl in rain. These measures may be achieved by testing under the meteorological conditions described in the PSD application. In addition to the wind and vertical temperature profile requirements, a short-term weather forecast of no rain for at least 2-4 hours after the test would also be required, depending on wind speed and atmospheric stability class. This would allow the plume to dissipate to such a degree that any rain after the 2- to 4-hour period would show no measurable increase in acidity due to HCl in the plume. To ensure that ASRM testing will produce the least possible impacts on the environment, NASA has adopted this concept. The meteorological conditions under which NASA will test the ASRM will be specified by the state of Mississippi as part of the PSD permit for which NASA has applied.

4.2.2 Surface Water

INTRODUCTION

This section explains the existing surface water conditions near SSC and the impacts due to ASRM testing under Case 1 meteorological conditions. Additionally, this section discusses the physical and chemical processes which govern the Case 1 impacts.

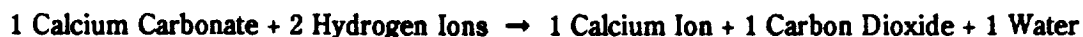
For this analysis, the constituents of interest in ASRM exhaust were grouped into two categories: 1) hydrogen ions (acid), and 2) aluminum compounds.

HYDROGEN ION

Chemical Principles: Hydrogen Ion

Acidity is an expression of hydrogen ion concentration and is measured in pH units. The pH scale ranges from 0 (most acidic) to 14 (least acidic or most basic). Values of pH near 7 are considered neutral, i.e., neither acidic nor basic. HCl, one of the exhaust products resulting from test firing the ASRM, is an acid. Effects of acid deposition into surface waters are dependent upon the characteristics of the acid fallout (such as pH and volume) and the surface water (such as pH, volume, and neutralizing capability). Such neutralizing capability, also known as buffering, is a result of the degree of alkalinity in the waters and soils. The neutralizing capability of the surface waters and soils is critical to determining the effects of acid deposition.

Surface water systems are dynamic, and their acidity is constantly being neutralized by several chemical compounds naturally present. The capability of surface waters to neutralize acidic inputs depends on the concentration and form of chemicals that contribute to alkalinity. Alkalinity generally refers to the neutralizing capability of waters, and may be approximated as follows:



The equation indicates that each unit of calcium carbonate combines with two units of hydrogen ion to form calcium, carbon dioxide, and water; that is, the acidity of the water is decreased by the removal of hydrogen ions. Measurements of alkalinity are expressed in milligrams of calcium carbonate per liter of water (mg CaCO₃/l); hereafter referred to as "units".

Existing Conditions: Hydrogen Ion (pH)

The water quality monitoring program now at SSC is conducted by NASA, and includes monitoring temperature, dissolved oxygen, pH, and other parameters. Data from late 1985 to mid-1988 were presented in the FEIS for various points in the Pearl River and Access Canal Spillway. Reported pH values ranged from about 5.5 to just over 8, depending on the monitoring point. In support of this SFEIS, water samples were collected at several additional points in and around SSC in April 1990 (Figures 4-4 and 4-5). The samples indicate a wide range of pH values of the surface waters (Table 4-6) from 4.6 at Standing Pine Bog to 7.1 at Lion Branch, with the geometric mean pH of all sampled sites equaling 6.1. Thus, both the long-term monitoring data and the small 1990 sample data indicate the waters in and around SSC are slightly acidic. The acidic nature of these waters is expected due to the high organic acid content in southeastern U.S. surface waters. Given the natural acidic nature of these surface waters, investigations focused on the ability of the waters to neutralize any additional acid inputs.

As noted earlier, the effects of acid deposition depend upon the alkalinity of the receiving water body. The existing monitoring program at SSC does not report alkalinity. Therefore, the eight samples collected at SSC in April 1990 were analyzed for alkalinity. Alkalinity values for SSC waters ranged from 5 units at one unnamed site (hereafter referred to as "northern branch of Devil's Swamp") to 124 units at Lion Branch. The average alkalinity at all sampled sites equaled 24.7 units. Alkalinity and pH data were also obtained for the groundwater supply for the Red Fish Hatchery. The Red Fish Hatchery is located within the SSC buffer zone approximately 3 miles northeast of the ASRM test stand. Table 4-6 summarizes the site-specific water quality data, including alkalinities.

The low alkalinity measured in the sample from the northern branch of Devil's Swamp (5 units) indicates a potential for pH depression (increased acidification) due to acidic inputs. An alkalinity of 5 units is calculated to have the capability of neutralizing 0.0001 unit of hydrogen ion/l of water (see Appendix C). The average (geometric mean) alkalinity at all sampled sites equaled 24.7 units, corresponding to a neutralizing capability of 0.0005 unit of hydrogen ion. As the alkalinity is increased from 5 to nearly 25 units, approximately five times more acid can be neutralized.

Predicted Conditions: Hydrogen Ion (pH)

Exhaust plume modeling has determined that where rain is not present (Case 1), no acid would be deposited and no change in the pH of surface waters would occur.

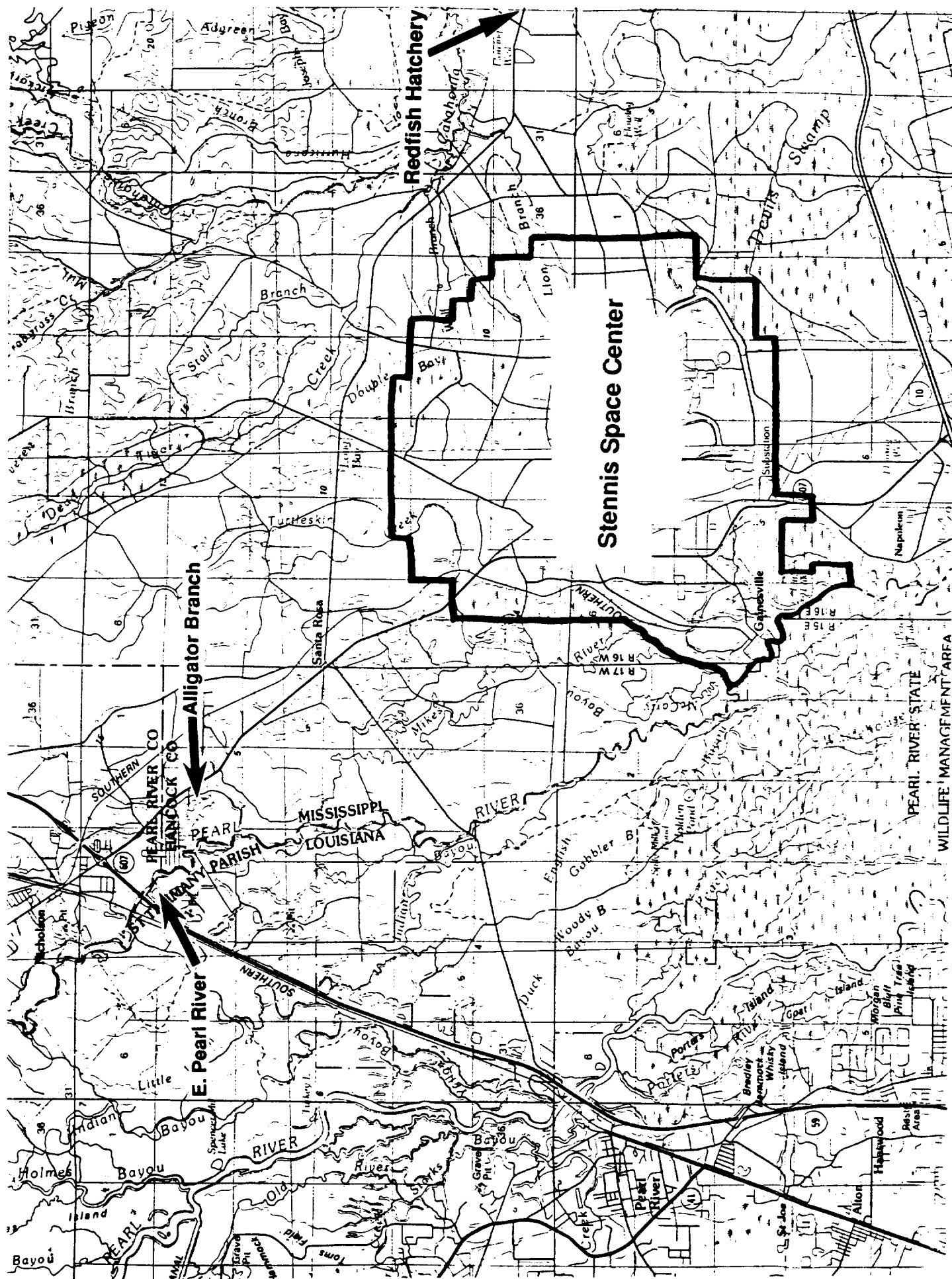


Table 4-6. Surface Water Quality Data, Stennis Space Center, Mississippi, April 1990.

Site	<u>Aluminum (mg/l)</u>		pH ^{a/}	Alkalinity (mg CaCO ₃ /l) ^{b/}
	Total	Dissolved		
Alligator Branch	1.30	0.48	6.1	31
Access Canal	1.50	0.71	6.8	34
Northern Branch Devil's Swamp	0.87	0.53	5.8	5
Devil's Swamp	0.10	0.07	6.5	45
E. Pearl River	2.00	0.44	6.3	12
Lion Branch	4.60	1.60	7.1	124
Standing Pine Bog	3.10	0.53	4.6	20
Wolf Branch	1.40	0.62	5.6	20
Geometric Mean	1.30	0.48	6.1	24.7
Red Fish Hatchery ^{c/}	NA	NA	5.4	166

a/ pH values rounded to nearest 0.1 unit, EPA method 150.1

b/ EPA method 310.1

c/ Red Fish Hatchery water quality data analyzed on June 16, 1988. Supplied by R. Hunt. NA = not analyzed.

ALUMINUM

Chemical Principles: Aluminum

The other major exhaust product of concern is aluminum oxide, one form of aluminum. The chemistry of all forms of aluminum in surface waters is more complex than that of many other metals because of several properties, including the following:

- Aluminum is more soluble (more easily dissolved, and hence more likely to be bioavailable) in acid (i.e., pH less than 4.0) and basic (i.e., pH greater than 8) solutions than in solutions with a near-neutral pH (i.e., between 6 and 8). Bioavailability refers to those chemical forms that can be taken up by aquatic organisms. Only bioavailable forms have the potential to cause harm to aquatic organisms.
- Some ions that may exist in surface waters, such as chloride, fluoride, and nitrate form soluble complexes with aluminum.
- Fulvic and humic acids (acids commonly found in nature as the result of decomposition of dead organisms or other organic matter, especially leaves) form stable, essentially nontoxic complexes with aluminum.
- Hydroxide ions can combine with aluminum ions and form both soluble and insoluble (potentially toxic and nontoxic) polymers (chains of molecules attached in a repetitive sequence).
- Aluminum and water approach equilibrium (chemical stability) relatively slowly (EPA 1988a).

Most of the properties stated above are pH dependent, and therefore an understanding of aluminum/pH interactions is important to accurately determine the effects of acid and aluminum in water.

Aluminum is the most abundant metallic element in the earth's crust, but the free metal (i.e., Al) is not found in nature because of its tendency to combine with other chemicals (Bodek et al. 1988). Aluminum can exist in many forms or species, with speciation and solubility being pH dependent. The solubility of aluminum increases exponentially with decreasing (and increasing) pH as compared to neutral solutions (EPA 1988a). Soluble aluminum is that part of the total aluminum that may be partially bioavailable and therefore potentially toxic to aquatic organisms, such as fish. It is important to note that the term "toxic" refers to the potential for a chemical (including metals) to harm aquatic life if the chemical is present at high enough concentrations and if it is in a bioavailable form. It does not mean that any amount of the metal is harmful.

Chemical Forms of Aluminum

As stated above, aluminum can exist in many forms or species. Some of these species are known to be toxic while others are harmless. Seip and others (1984) stated that the most toxic species of aluminum are the simple hydroxides, while organically bound aluminum and polymer species are either less toxic or essentially harmless. One form of aluminum is aluminum oxide. Under natural conditions, aluminum oxide is not a source of toxic aluminum species due to its stability. Therefore, this form is not bioavailable.

The majority (more than 99 percent) of aluminum in ASRM exhaust is present as aluminum oxide. All the aluminum oxide in the exhaust is nonfibrous (Cofer et al. 1987). EPA has determined that nonfibrous aluminum oxide is nontoxic (EPA 1990). Thus, the predominant aluminum form present in the ASRM exhaust would be harmless in its initial state. In addition to looking at the initial form of aluminum oxide in the emissions, the remaining fraction of aluminum forms present in the exhaust and of chemical reactions that could alter the form of the aluminum oxide were evaluated.

The aluminum oxide that is present in ASRM exhaust exists in two predominant forms called alpha and gamma. Alpha and gamma are chemistry terms that refer to the physical structure, or orientation in space, of a compound. Over 72 percent of ASRM aluminum oxide measured during Space Shuttle launches was found to be the alpha form (Cofer et al. 1984). The alpha form of aluminum oxide is insoluble in both water and hot concentrated acids (Cofer et al. 1984). This means it would not react to form potentially harmful aluminum forms. The gamma form is insoluble in water but contrasts with the alpha form because it can be solubilized with acids. The gamma form of aluminum oxide may be solubilized under acidic conditions and may be converted to a biologically available form. Cofer et al. (1984) verified that water soluble forms of aluminum oxide resulted after exposure of gamma aluminum oxide to gaseous HCl and water mixtures. The conversion of gamma aluminum oxide to water soluble forms is dependent on the acidity of the environment that it is in. That is, a higher percentage of the gamma aluminum oxide would be converted to a soluble form in a very acidic environment than would be converted in a less acidic environment.

Existing Conditions: Aluminum

To determine the form and amount of aluminum compounds that already exist in the environment around SSC, water quality samples collected at SSC in April 1990 were analyzed for total and dissolved aluminum. Total aluminum includes species that are soluble and potentially bioavailable (such as the gamma forms and chlorinated aluminum compounds) and those that are insoluble and not bioavailable. Measurements of dissolved aluminum are better than total aluminum measurements for indicating bioavailability and the potential to harm aquatic organisms. While the amount and form are important, this information alone is not adequate to predict toxicity. For example, even within the dissolved fraction, both bioavailable and organic acid-complexed species that are not bioavailable are commonly measured. The organic acid-aluminum complexes are considered nontoxic (EPA 1988a).

As noted in Table 4-6, total aluminum concentrations of surface water samples collected at SSC in April 1990, ranged from 0.10 to 4.60 mg/l, with a geometric mean of 1.30 mg/l. Dissolved aluminum concentrations in the samples ranged from 0.07-1.60 mg/l, with a geometric mean of 0.48 mg/l. These data indicate high levels of aluminum under existing conditions; the mean dissolved concentration of aluminum at SSC, 0.48 mg/l, substantially exceeds the mean of U.S. surface waters, 0.74 mg/l (Bodek et al. 1988). Naturally occurring high aluminum levels in surface waters are common in the acidic waters of southeastern swamps and marshes. Whether the natural levels of aluminum may be sufficiently high to affect aquatic life is assessed on a site-specific basis. On the basis of existing measurements, it is not possible to state how much of the dissolved aluminum present is the organic-acid complex (and thus nontoxic) form. However, the presence of aquatic life in sampled waters from SSC which contain high levels of organic acids and high dissolved aluminum concentrations suggest that most of the aluminum present is in the complexed benign form. Although the presence of aquatic life does not ensure a healthy ecosystem, there are no indications that the aquatic environment in and around SSC is stressed in any observable manner.

Predicted Conditions: Aluminum

The analysis of aluminum deposition from ASRM testing considered all known toxic and potentially toxic species of aluminum. The deposition of aluminum oxide due to test firing the ASRM, modeled under Case 1 conditions, led to a predicted deposition of aluminum oxide equal to approximately 1.07 to 1.56 mg/m² (Table 4-4). As noted earlier, aluminum oxide is not considered toxic under natural conditions but may contribute potentially harmful species of soluble aluminum forms under acidic conditions (Cofer et al. 1984). Evidence is sparse for toxicity determinations of aluminum compounds other than those known to be toxic (i.e., free aluminum, soluble hydroxy complexes, and complexes with chloride). Because data are lacking for other aluminum compounds, this analysis conservatively assumed that these other aluminum species would be potentially soluble and therefore toxic if the possibility existed for chemical reactions to generate known toxic soluble species.

Because aquatic environments are chemically complex, calculating expected changes within the surface waters requires constraining the less critical variables and concentrating on those variables that are expected to have major influences on the system. These constraints, or assumptions, follow:

- Assume that the small percentage of aluminum compounds other than aluminum oxide present in ASRM exhaust are potentially toxic.
- Assume the ratio of aluminum oxide to other aluminum compounds present in ASRM exhaust remains constant.
- Assume aquatic toxicity of aluminum compounds is directly related to the release of free aluminum ions.

Some aluminum can be mobilized from sediments and soils under acidic conditions, with the degree of mobilization being pH dependent in most cases. Maximum mobilization is expected at pH below 4.0, with decreased mobilization expected as acidity decreases; i.e., at higher pHs. The mobilized aluminum forms strong complexes with hydroxide, fluoride, sulphate, and dissolved organic ligands (Driscoll et al. 1980). The organic ligands include humic and fulvic acids, which are a common constituent of acidic surface waters, especially swamps and bogs. The waters and soils of SSC are relatively acidic due to these acids. It is expected that some of any additional aluminum entering surface waters as a result of ASRM testing would be complexed by the organic acids. The organic acid/aluminum complexes that formed would result in decreased availability of aluminum to aquatic life, minimizing any potential for impact.

Exhaust plume modeling predicted aluminum chloride depositions that ranged from 0.00016 to 0.00023 mg/m² (Table 4-4). The maximum deposition of 0.00023 mg/m² of aluminum chloride, added to typical surface waters, results in augmenting aluminum concentrations in the water by less than 0.000001 mg Al/l.

It is difficult to quantify the portion of aluminum oxide that reacts with HCl to form additional toxic aluminum species. The most conservative approach assumes that all of the aluminum oxide deposited has reacted with HCl (i.e., disregarding the probable chlorination of only the gamma portion of aluminum oxide). With this extremely conservative assumption, the deposition of 1.56 mg of aluminum oxide per square meter equals approximately 0.0054 mg Al/l at a water depth of 6 inches. The significance of this deposition is discussed below.

Comparison of Existing and Predicted Conditions: Aluminum

Existing aluminum levels in the surface waters were compared to those levels of aluminum that serve as limits of protection for aquatic life. These protective concentrations are referred to as water quality criteria. The EPA has published water quality criteria for many chemicals designed to protect aquatic life in the nation's fresh waters. The criteria specify acceptable levels of a given chemical that, if not exceeded, would be protective of aquatic life. Criteria are established for both short-term (acute) and long-term (chronic) conditions.

Both the acute and chronic water quality criteria were considered. The acute criteria would be appropriate immediately after an ASRM test. The chronic criteria can be used to evaluate cumulative or long-term effects. The acute criteria of 0.75 mg Al/l should not be exceeded for more than 1 hour within a three-year period. The chronic criterion of 0.087 mg Al/l should not be exceeded for more than 4 days within a three-year period. The lower chronic value was set to protect two sensitive and important species, rainbow trout and striped bass. Striped bass may be found in several of the rivers in and around SSC, including the Pearl River and its tributaries.

The naturally occurring dissolved aluminum concentrations at SSC (Table 4-6) exceed the EPA chronic aluminum criterion (0.087 mg/l) for all sampled surface waters except the Devil's Swamp sample, which was found to be slightly below the chronic criterion level. However, as stated previously, toxic effects are not readily apparent at this time. The apparent lack of toxicity of surface waters under present conditions may be due to a number of reasons including:

- While the total dissolved aluminum value may exceed the criteria, only a portion of the dissolved aluminum measured is available to organisms (bioavailable).
- The water quality criteria are established to protect certain sensitive species. While striped bass are expected to exist in surface waters around SSC, other species native to the area may be more resistant. Native populations of aquatic organisms include those organisms that are acclimated to natural conditions associated with southern surface waters, such as naturally occurring high aluminum levels and high acidity.
- The criteria for aluminum are based on waters with pH values in the range of 6.5 to 9.0. The aluminum criteria may not apply to waters with pH values outside these limits, such as some of the more acidic waters commonly found in the southeastern states. The EPA recognizes that at pH values below 6.5, specific conditions associated with the site waters (organic acid content, hardness, and so forth) may be critical for establishing pH/aluminum toxicity relationships (EPA 1988a).

CONCLUSIONS

Under Case 1 conditions, where rain would not be present, no measurable depositions of acid, and therefore no change in acidity of surface waters, is expected either in the vicinity of SSC or elsewhere.

Aluminum depositions were predicted to total less than 0.0060 mg/l in surface waters. The organic acids present in local surface waters should greatly reduce bioavailability (via complexation) of the naturally occurring high aluminum levels and any additional inputs that may result from ASRM testing. Although aluminum concentrations in sampled surface waters at SSC are relatively high (compared to the national average and the EPA acute water quality criterion), the bioavailable portion of the total aluminum present in these waters appears to be low. Many of the natural waters at SSC obviously support aquatic life, including the sensitive striped bass species. There is no information currently available that indicates the natural aquatic environment is stressed. Additional inputs would be minimal and they are not expected to result in any adverse impacts to aquatic life.

4.2.3 Aquatic Life

INTRODUCTION

In Europe, the northeastern United States and southeastern Canada, researchers have identified acid rain effects on aquatic life, as well as acid-rain induced increases in aluminum concentrations in lakes and streams. Since the impact to aquatic populations due to acid rain involves chemicals that are emitted during ASRM testing, concerns have been voiced regarding the potential for similar impacts to aquatic populations in the vicinity of SSC. Concerns have also been voiced regarding the potential toxicity of aluminum chloride.

The FEIS concluded the impacts of ASRM testing on fish would be insignificant because only small, localized impacts on water quality were predicted. Because of additional air quality modeling, additional data have been collected and modeled to better characterize existing and expected water quality conditions (Section 4.2.2). In addition, relevant studies of the effects of aluminum and acids on aquatic life have been thoroughly reviewed. This review confirms earlier analysis which predicted insignificant impacts to aquatic populations.

The following discussion of effects on aquatic life summarizes the ways in which acid and aluminum can affect aquatic species, current state of knowledge on the subject, and finally, expected effects of ASRM testing on aquatic species under Case 1 expected conditions.

ADDITIONAL INFORMATION

The potential effects of ASRM exhaust emissions on fish and amphibian health is very complex, involving interactions between a number of chemicals, primarily hydrogen ions (acid), calcium, and select forms of aluminum. The interaction of these chemicals as they affect toxicity has been the subject of considerable research in recent years. The majority of investigations have been conducted in European and northeastern North American lakes and streams where problems with acid rain have been identified. In contrast to the surface waters around SSC, the European and northeastern North American lakes are typically cold and clear with minimal buffering capacity (that is, minimal ability to chemically neutralize additions of acid; see Section 4.2.2).

Because the effect of calcium, alkalinity, and some forms of aluminum on the toxicity of increased acidity levels was unknown until the last several years, early investigators often failed to measure or report alkalinity, calcium concentrations, and/or aluminum concentrations in their research. Where aluminum was reported, the exact form of aluminum was often omitted. As a result, the reported results of these early investigations were highly variable. Over the past decade, as the role of various metals on toxicity has become better understood, researchers have made a greater effort to account for the effects of metals in their studies. Although a great deal of variability continues to be found in study results, general patterns have emerged which can be used to address the potential effects of increased acidity and increased aluminum concentrations.

Research conducted in recent years has concentrated on trout and salmon species because these species have been identified as sensitive to increased acidity and because they are the most common game fish in northern waters. Few studies have been conducted on species of importance in southern Mississippi. The ability to identify potential impacts on aquatic species from ASRM testing at SSC is, therefore, limited by the availability of information regarding the specific warm water species present in the area. There is, however, sufficient similarity in the toxicity of acid and aluminum between species to allow extrapolation of species in the project area where actual species-specific data are not available.

Summarized below are the most relevant studies concerning the toxic effects of acid and aluminum on aquatic species. The discussion includes a generalized description of how acid and aluminum can affect aquatic species, including the effect that calcium has on modifying toxic effects. This generalized discussion is followed by the results of research on specific species either found in the ASRM testing region or related to species found in the area.

Effects of Increased Acidity

Reported effects of low pH on fish have been highly variable. Death due solely to high acid concentrations, accounting for other factors which may affect mortality, has seldom been tested. Generally, it is believed that death related to increased acidity in the water is caused by different mechanisms, depending upon the pH of the water. Below approximately pH 4.0 to 4.5 (depending upon the species of concern), the blood may become acid, affecting oxygen transfer to the tissues and causing death (Wood 1989).

When the water acidity is in the range of approximately pH 4.0 to 6.0 (variable between species), it is generally believed that the transfer of electrolytes (chemicals important to the maintenance of proper moisture and salt balance in the tissues) is affected, which results in stress and may cause death. At moderately low pH levels which are not inherently lethal, high feeding rates are needed to compensate for low pH stress; if the feeding rate is not high enough, reduced growth occurs (Brown and Sadler 1989). Reduction of fish populations caused by impaired egg development and reduced ability of female fish to release their eggs has also been observed when moderately acid, nonlethal conditions are present (Bonga and Balm 1989).

The presence of calcium in the water can act to reduce the effects of acid by blocking the loss of electrolytes from the tissues and positively affecting other physiological processes (Wood 1989; Potts and McWilliams 1989; Howells et al. 1983; McDonald et al. 1989). As a result, fish can generally tolerate greater concentrations of acid when calcium is present in sufficient quantities. In an analysis of the ratio of calcium to hydrogen ions (acid) in lakes, Brown and Sadler (1989) found the majority of fishless lakes to have a ratio of calcium to hydrogen of less than 3 to 1; the majority of lakes with good fisheries tended to have a ratio greater than 4 to 1.

Sensitivities of amphibians to acid exposure have been found to be similar to the sensitivities of fish. Amphibians are most susceptible during the egg stage of development. Of the species observed at SSC, salamanders have been noted to be sensitive to surface water pH values below 5.0. The eggs of the northern leopard frog, a species closely related to the southern leopard frog found at SSC, experience 50 percent mortality at pH near 5.0 (Pierce 1985). Long-term exposures of sublethal pH levels have also been shown to inhibit growth of amphibians (Clark and La Zerte 1985; Pierce 1990).

Effects of Aluminum at Low pH

The harmful effects of aluminum are highly dependent upon the form of aluminum in water (Section 4.2.2). The bioavailable forms of aluminum refer to those chemical forms that can be taken up by aquatic organisms. Only bioavailable forms have the potential to be harmful to aquatic life. Bioavailable aluminum in concentrations greater than 0.25 mg/l is generally most toxic around pH 5.1 to 5.5, a level at which acidity is not acutely lethal (Brown and Sadler 1989; Potts and McWilliams 1989; Wood 1989; Reader and Dempsey 1989).

In addition to the toxicity associated with selected forms of aluminum, aluminum polymers and precipitates are thought to coagulate at or absorb onto the gill surface, which can cause damage and possibly asphyxiation (Kane and Rabeni 1987; Wood 1989).

Effects of Aluminum Chloride

Results of numerous studies indicate a 50 percent mortality can be expected when aquatic organisms are exposed to concentrations ranging from approximately 0.20 mg aluminum chloride/l (approximately 0.050 mg Al/l) for the narrow-mouthed toad to approximately 108.00 mg aluminum chloride/l (approximately 27.00 mg Al/l) for mosquito fish (EPA 1988a).

Species-Specific Toxicity Data

A selection of applicable species-specific study results as reported by investigators and reviewers has been summarized in Table 4-7 as an aid in interpreting any toxic effects which may occur at pH levels below 6.5 due to the interaction between aluminum, calcium, and acid concentrations. For most of the studies listed on Table 4-7, the calcium concentration or alkalinity is unknown, reducing their value in interpreting the potential effects of increased aluminum and/or acid on fish populations. In addition, only one of the studies [concerning sticklebacks (Burrows 1977)] identified a range of minimum concentrations which resulted in effects. Most of the studies reported results of specific concentrations selected prior to testing rather than testing for threshold conditions. As a result, little information is available regarding the minimum concentrations at which effects may occur.

Table 4-7. Summary of study results on toxicity of acid and aluminum to aquatic species.

Species	pH	Ca/Alkalinity	Aluminum	Results	Reference
Smallmouth Bass (<i>Micropterus dolomieu</i>)	5.1 6.1-7.5	Unknown Unknown	> 0.18 mg/l > 0.18 mg/l	100% mortality <20% mortality deformities abnormal behavior reproduction failure	Beamish 1976 as cited by Kane and Rabeni 1987
Larval White Suckers (<i>Catostomus commersoni</i>)	4.2-5.6	Unknown	0.1 mg/l	Significant mortalities	Baker and Schofield 1982 cited by Kane and Rabeni 1987
Goldfish (<i>Carassius auratus</i>)	7.6 6.8	hard water hard water	1 mg/l 10.5 mg/l	Not lethal lethal in 12-96 hrs	Burrows 1977 Burrows 1977
Largemouth Bass (<i>Micropterus salmoides</i>)	5.6 4.5	64-80 ppm (hardness) 64-80 ppm (hardness)	8 mg/l 20 mg/l	Not lethal Lethal in 8-23 hrs	Burrows 1977 Burrows 1977
Bluegill (<i>Lepomis macrochirus</i>)	5.6 3.0-3.5 4.5-7.5 4.5 5.5 6.5 and 7.5	64-80 ppm (hardness) Unknown 6.9 mg/l Ca ²⁺ 6.9 mg/l Ca ²⁺ 6.9 mg/l Ca ²⁺ 6.9 mg/l Ca ²⁺	8 mg/l Unknown 0-0.2 mg/l 0.4 mg/l 0.4 mg/l 0.4 mg/l	Not lethal 50% mortality in 96 hrs Not lethal in 4 days 26.7% mortality in 4 days 73.1% mortality in 4 days 0% mortality in 4 days	Burrows 1977 Elgaard and Gilmore 1984 Palmer et al. 1988 Palmer et al. 1988 Palmer et al. 1988 Palmer et al. 1988
Stickleback (<i>Gasterosteus aculeatus</i>)	7.0 5.2	Unknown Unknown	0.07 mg/l 0.30 mg/l	Minimum lethal dose High mortality	Burrows 1977 Burrows 1977
Golden Shiners (<i>Notemigonus crysoleucas</i>)	3.7 4.5 5.0 5.0	Unknown Unknown Unknown Unknown	0 mg/l 0 mg/l 0 mg/l 100 ppm	100% mortality 100% mortality in 15 days Not lethal 100% mortality	Robinson and Deano 1985

Table 4-7. Summary of study results on toxicity of acid and aluminum to aquatic species (continued).

Species	pH	Ca/Alkalinity	Aluminum	Results	Reference
Golden Shiners (continued) (<i>Notemigonus crysoleucas</i>)	7.0	Unknown	100 ppm	Slight depression in survival	
Fathead Minnows (<i>Pimephales promelas</i>)	5.2	soft water	0.06 mg/l	Reduced juvenile survival, spawning failure	McCormick et al. 1989
	6.5-7.5	6.9 mg/l Ca ²⁺	0-0.4 mg/l	Not lethal in 4 days	Palmer et al. 1988
	5.5	6.9 mg/l Ca ²⁺	0 mg/l	Not lethal	Palmer et al. 1988
	5.5	6.9 mg/l Ca ²⁺	0.05 mg/l	30% mortality in 4 days	Palmer et al. 1988
	5.5	6.9 mg/l Ca ²⁺	0.1-0.4 mg/l	100% mortality in 4 days	Palmer et al. 1988
	4.5	6.9 mg/l Ca ²⁺	0-0.4 mg/l	100% mortality in 4 days	Palmer et al. 1988
Channel Catfish (<i>Ictalurus punctatus</i>)	6.5-7.5	6.9 mg/l Ca ²⁺	0-0.4 mg/l	0% mortality in 4 days	Palmer et al. 1988
	5.5	6.9 mg/l Ca ²⁺	0 mg/l	0% mortality in 4 days	Palmer et al. 1988
	5.5	6.9 mg/l Ca ²⁺	0.1 mg/l	17.1% mortality in 4 days	Palmer et al. 1988
	5.5	6.9 mg/l Ca ²⁺	0.2-0.4 mg/l	100% mortality in 4 days	Palmer et al. 1988
	4.5	6.9 mg/l Ca ²⁺	0 mg/l	3.3% mortality in 4 days	Palmer et al. 1988
	4.5	6.9 mg/l Ca ²⁺	0.05-0.4 mg/l	82.9-96.7% mortality in 4 days	Palmer et al. 1988

EXISTING CONDITIONS

Water samples taken at SSC in April 1990 indicate that, generally, pH ranged from 4.6 to 7.1, and aluminum concentrations ranged from 0.1 to 4.6 mg/l (Section 4.2.2, Table 4-6). The pH values in this limited sample are similar to those observed during several years of water quality monitoring, indicating that they are representative of the water's current condition. Within the East Pearl River, Alligator Branch, Lion Branch Devil's Swamp, the Access Canal to SSC, and other untested drainages (Section 4.2.2, Figures 4-4 and 4-5), pH levels greater than 6.1 were recorded. These appear to provide satisfactory conditions for largemouth bass, bluegill, channel catfish, striped bass, and possibly other species regardless of the presence of aluminum or the portion of existing aluminum that may be in bioavailable forms. The pH of the groundwater supply to the Red Fish Hatchery equals 5.4 (Table 4-6), which obviously allows successful culturing of freshwater fish. Lower pH levels were found in some of the smaller drainages and swamp-like areas. In these areas, if all the dissolved aluminum were assumed to be bioavailable (in a form which fish can uptake into their tissues), literature study results suggest that conditions would not be conducive to bass, bluegill, fathead minnows, and channel catfish would occur within the existing range of water conditions. Regardless of the degree of bioavailability of the aluminum currently present in the region's smaller drainage areas, many of these water bodies are not expected to support fish because they are too shallow or are intermittent; that is, they dry up during part of each year. These intermittent water bodies may support other aquatic organisms, such as invertebrates and amphibians.

A review of the literature indicates that bluegill have the greatest tolerance to elevated aluminum and acid concentrations of the species tested. Bluegill are the only species important to sport or commercial fisheries that are reported to exist in the smaller drainages in the area (Esher and Bradshaw 1988). The tolerance of bluegill to acid and aluminum may, therefore, be the primary reason why they are the only key species found in significant quantities in the smaller drainages where lower pH levels were recorded.

Other species common in the vicinity of SSC include crappie, shiners, sunfish, madtom, paddlefish, and Atlantic sturgeon (*Acipenser oxyrinchus*). No studies addressing the toxic effects of aluminum and acid on these species were found. The majority of these species are found primarily in the larger drainages, suggesting a dependence on either the existence of deeper water, or flowing water, or higher pH levels.

CONCLUSIONS

Under normal operating conditions without rain, ASRM testing is expected to have no effect on pH and minor effects on aluminum concentrations on SSC surface waters (Section 4.2.2). The trace amounts of aluminum (less than 0.0060 mg/l increase) are insignificant relative to the levels naturally present in the region's drainages and relative to the minimum level of aluminum required to produce toxic effects. These concentrations would have no impacts on fish populations.

The predicted deposition of aluminum chloride associated with ASRM testing corresponds to an aluminum chloride concentration in shallow surface waters (6 inches or less) of less than 0.000005 mg/l (approximately 0.000001 mg Al/l). That is, the deposition of aluminum chloride is expected to be approximately 40,000 times less than the minimum concentration causing 50 percent mortality in laboratory tests with toads. Because the concentration of aluminum chloride is so far below the level that would harm aquatic species, no adverse effects on aquatic life are expected due to aluminum chloride exposure.

Even greater-than-predicted acid deposition in areas such as the access canal, Catahoula Creek, the main channels of the Pearl River, or Alligator Branch would have no effect on aquatic life because these areas have sufficient volume and/or flow to accept acid increases without changing the natural acidic balance of the water. Greater-than-predicted deposition of aluminum compounds would have no effect because increases in aluminum concentrations 100 times as great as predicted would continue to be unsubstantial relative to existing aluminum concentrations. In conclusion, no impacts are predicted on aquatic populations under expected Case 1 operating conditions.

4.2.4 Plants and Soils

INTRODUCTION

As concluded in the FEIS, static testing impacts on vegetation and soils in and adjacent to the ASRM test site at SSC are expected to be below threshold levels that would cause harm to plants or decrease soil fertility. Additional information is presented here to describe the natural processes and project-related practices that will prevent adverse impacts. This supplemental analysis substantiates initial conclusions in the FEIS that ASRM test emissions under expected conditions will not adversely impact vegetation and soil fertility.

SUMMARY OF THE FEIS

As noted in the FEIS and in Section 3 of this SFEIS, a vegetation analysis was completed at SSC by Esher and Bradshaw in 1988. They identified four major plant community types on the proposed ASRM site: 1) pine forest; 2) bottomland hardwood forest; 3) pitcher plant bogs; and 4) grasslands (Esher and Bradshaw 1988). Vegetation in the buffer area and region around SSC is primarily pine forest and bottomland hardwood forest. Pitcher plant bogs, bottomland hardwood forests, and much of the pine forest can be classified as wetland.

Vegetation resources can be affected by direct deposition of emission substances on plant surfaces (short-term or acute effects), or by deposition of emissions on soils and surface waters that causes changes in soil and/or water chemistry affecting plant growth and survival over time (long-term or chronic effects). The FEIS discussed potential impacts to vegetation for the major emission products, aluminum oxide and HCl gas. Based on a review of studies that investigated the effects of aluminum oxide exposures to plants, the FEIS concluded that impacts to vegetation from aluminum oxide air concentration or

deposition would be insignificant. No studies reviewed during preparation of the FEIS had demonstrated any visible effects on plants from high doses of aluminum oxide (Lerman et al. n.d.; NASA 1977; NASA 1980).

As noted in the FEIS, the likelihood, type and extent of injury to plants from HCl gas are dependent upon plant species, HCl concentration, and exposure time. A number of studies have documented the reaction of plants to HCl exposure (Lerman et al. n.d.). The FEIS concluded that if HCl were rained out at the point of greatest concentration, the effect on plants would be minor because this concentration and duration of exposure are below doses of HCl that cause observable injury to plant foliage. Leaf discoloration and spotting could occur only during atmospheric conditions of calm wind and rain, conditions under which NASA does not plan to test.

ADDITIONAL INFORMATION

Additional information documenting the relative toxicities of HCl, aluminum oxide, and other emission products was obtained to further evaluate the potential for environmental impacts described in the FEIS. This information and impact assessment focuses on potential acute and chronic effects of the emissions. Specifically, this section addresses the following plant-related concerns: 1) potential acute and chronic effects of aluminum oxide deposition on plant parts; 2) potential acute effects of HCl air concentrations on plants; 3) potential acute effects of HCl deposition on plants; and 4) potential chronic effects on plants from HCl deposition on soils.

Aluminum Oxide Deposition on Plant Parts

As noted in Section 4.2.1, aluminum oxide is not toxic, but can be characterized as a particulate emission. Particulate emissions are not generally considered harmful unless they are highly caustic or if very heavy deposits occur (Jacobson and Hill 1970). Aluminum oxide is not caustic, nor will ASRM testing produce heavy deposits of aluminum oxide. Instead, the maximum deposition of aluminum oxide will be small (1.56 mg/m², Table 4-4).

Because aluminum oxide is an inert substance, effects could occur only if aluminum oxide deposits were large enough to coat leaf surfaces, thereby blocking light available for photosynthesis and plugging the leaf pores used for gas exchange in plant respiration. Again, the projected maximum rate of aluminum oxide deposition (about 1.56 mg/m², see Table 4-4) will not approach the quantities required to coat leaf surfaces and produce such chronic effects.

Potential Acute Effects of HCl Air Concentration on Plants

As stated above, the likelihood and extent of injury to plants from exposure to HCl gas depends on plant species, HCl concentration and exposure time. In high concentrations, HCl gas can be toxic to plants in both gaseous and aqueous forms. No chronic effects have been reported for HCl gas (Jacobson and Hill 1970), although extremely high gaseous HCl concentrations have been shown to cause acute plant injury. Endress and others (1978) exposed pinto bean leaves for 20 minutes to different concentrations of HCl gas, and noted dead spots only on leaves treated with HCl concentrations higher than 17.9 mg/m³. Concentrations in excess of 25.0 mg/m³ were required to induce dead spots on more than 10 percent of the leaves.

Under Case 1 conditions, the maximum ground-level air concentration of HCl resulting from ASRM testing is predicted to be 0.24 mg/m³, 0.6 mile (1 km) from the test stand (Table 4-3). This indicates that HCl concentrations produced during ASRM testing under Case 1 conditions at SSC will be some 75 times less than threshold levels at which plant leaves might begin to show damage. Predicted HCl gas concentrations in the air will therefore not cause any acute effects to plants. Under expected conditions (Case 1) there will be no measurable HCl deposition and therefore no deposition impacts on plants.

Potential Chronic Effects on Plants from HCl Deposition in Soils.

Existing Soil Conditions. The soils in the SSC area are predominantly hydric or wetland soils (USDA 1981). These soils are characterized by low pH and high levels of organic matter within the top 6 inches of soil. Soils contain substantial amounts of organic acids, as evidenced by the brown color of many surface water bodies in and around SSC. Organic matter plays a key role in buffering soils from changes in pH, and organic acids have a major role in immobilizing soluble aluminum compounds produced by low pH (Hue et al. 1986).

NASA is developing a comprehensive program for monitoring soil conditions. While the environmental monitoring plan is being developed, some monitoring has been initiated to characterize the existing soil condition. In the summer of 1989, soil samples were taken from six locations on the SSC fee area. At each location, three independent (replicate) samples were obtained from each of the four soil layers (horizons) which were present. These samples, in combination with a larger number of samples to be taken over the next three years, will be used to characterize the soil materials before any ASRM testing is conducted and will provide a baseline for later comparison with post-test conditions. To predict ASRM effects on soils, tests were performed on the 1989 soil samples to characterize percent of organic matter, pH, cation exchange capacity (CEC), available (exchangeable) aluminum, and layer thickness.

A preliminary summary of the 1989 test results (NASA 1990b) indicates that the surface layer (variable depth leaf litter or organic horizon) has high organic matter content (50 percent), high cation exchange capacity (an expression of a soil's buffering capacity and other conditions) (23 meq/100g), low pH (3.5 at upper soil layers), and moderately high

exchangeable aluminum content (372 ppm). Twenty-five percent of the sampled soil's available cation exchange capacity is used by the existing aluminum (25 percent aluminum saturation). Cation exchange capacity refers to the ability to resist changes in acidity; the higher the cation exchange capacity, the greater the ability to buffer changes in acidity.

Other sampled layers below the surface layer showed less organic matter (8 percent in the A horizon, the first mineral soil layer below the organic layer, with an accumulation of clays down to 0.5 percent in the B2 horizon, the next lower layer), moderate cation exchange capacity (about 7 meq/100g), less acid (pH 4.1 to 4.6), and less aluminum (about 220 ppm). The aluminum saturation is about 40 percent.

Potential Soil Effects from HCl Deposition. The extent and likelihood of impacts to soils from HCl deposition can be explained by three mechanisms: 1) increased acidity (decreased pH) could result in an increase in aluminum solubility; 2) interaction of HCl and aluminum oxide could produce bioavailable aluminum compounds; and 3) soil fertility could decrease (by replacement of nutrient minerals important for plant growth with hydrogen ions).

1. *Increases in Acidity and Aluminum Solubility.* Deposition of HCl onto soils and the likelihood of lowering soil pH (increased acidity) depends on initial soil pH, quantity of HCl deposited, soil type, predominant clay mineral, soil and vegetation buffering abilities, rates of organic acid release to soil from decomposition processes, and the size of the watershed drainage area. Soils have the ability to buffer changes in acidity, depending on the amount of organic matter present and the predominant type of clay mineral in the soil.

Increased soil acidity may also increase the solubility of aluminum, which can be harmful to some plants if it occurs in high enough concentrations (Cronan and Schofield 1979). Exchangeable aluminum generally becomes more soluble as the pH decreases below 4.0 or increases above 8.0, and gradually increases to toxic levels for some plants at pH values less than 5.0 in most soils. Symptoms of aluminum toxicity may include stunting, discoloration (purpling), appearance of small and excessively dark green leaves, leaf curl, and stubby/brittle roots (for more discussion on aluminum chemistry, see Section 4.2.2).

Bioavailable aluminum is immobilized (or bound) by organic acids present in the soils, by their binding with these acids to form insoluble or nonbioavailable molecules (Foy 1971). As bioavailable aluminum increases with a lowering of the pH, aluminum species not tied up in an organic molecule complex ultimately migrate to water bodies. Thus, organic matter present in the soil provides a binding capacity for changes in soluble aluminum. In general, the higher the amount of organic matter, the higher the soil's binding capacity. As noted above, the soil samples recently taken at SSC indicate a high binding capacity in the surface layer due to high organic matter (NASA 1990b).

2. ***Toxic Aluminum Forms in Soils.*** The formation of bioavailable aluminum compounds, generally regarded as potentially toxic forms of aluminum in aqueous systems, depends on the reaction of HCl from the exhaust plume or other existing mineral acids such as nitric and sulfuric acid with soil aluminum (Fageria et al. 1988). While small amounts of chlorinated aluminum compounds will be present in the ASRM exhaust, essentially all will be immobilized by the natural buffering capacity in the soil (Adams 1990).
3. ***Decreases in Soil Fertility.*** Soils receiving acid deposition and increasing amounts of soluble aluminum may undergo a loss of fertility as the hydrogen and aluminum ions replace (exchange) ions of nitrogen, calcium, potassium, and magnesium, all important nutrients for plant growth. A soil's ability to buffer changes in fertility is determined by the type of clay predominating in the soil and by the amount of organic matter.

Plant-Soil Interactions Related to ASRM Testing. To further clarify the effects on plants of changes in soils caused by deposition of aluminum oxide and acid, a review of the literature was conducted and then discussed with Dr. James Adams, an expert in soil chemistry who is knowledgeable about aluminum and acidic conditions in Mississippi soils.

Dr. Adams, a professor at Auburn University, stated that the organic acids in the local soils will combine (complex) with soluble forms of aluminum which may be deposited or produced and will immobilize the aluminum (Adams 1990). This is especially true in forested areas where leaf debris accumulation leads to production of organic acids; and it is also true in grassy areas (pasture). Bioavailable aluminum forms are immobilized by organic acids present in organic layers of the soil (Foy 1971). In agricultural soils low in organic matter, such as row crops, farmers typically lime their fields to reduce soil acidity that is naturally occurring or induced by commercial fertilizers, thereby avoiding any problems with aluminum toxicity.

On the basis of air quality modeling results discussed in Section 4.2.1, maximum deposition rates of aluminum oxide are projected to be approximately 1.56 mg/m² at a distance of 4.2 miles under the normal conditions of no rain (Case 1). The maximum predicted value of 1.56 mg/m² deposition of aluminum oxide for each test is equivalent to 0.0078 pound of aluminum per acre (aluminum oxide is about half aluminum). On the basis of the average of the organic horizon samples taken in 1989, the total amount of exchangeable aluminum in the top 6 inches of soil is currently close to 900 lb/acre. Aluminum oxide and aluminum chloride (about 0.00023 mg/m², Table 4-4) depositions are expected to be too small to alter the natural chemical balance of local soils.

CONCLUSIONS

The FEIS concluded that no adverse impacts would occur to vegetation from ASRM testing under expected conditions. This supplemental analysis, based on additional modeling, supports these conclusions. Air concentrations and deposition rates of HCl, aluminum

oxide and aluminum chloride are below the threshold levels at which research has shown are harmful to plants. Aluminum oxide is nontoxic even in high doses.

The incremental quantity of aluminum added to the soil from ASRM testing is small enough in comparison to the natural amounts of aluminum already found in the soil that it can easily be assimilated without changing the chemical properties of the soil. In addition, organic acids in the soil will combine (complex) with most if not all toxic forms of aluminum which may form and immobilize them, similar to natural conditions.

4.2.5 Groundwater

INTRODUCTION

The SFEIS addresses two groundwater issues: 1) the impact of ASRM testing on groundwater quality and 2) the potential for damage to water wells from vibrations generated during testing. The FEIS concluded that the potential for impacts to shallow groundwater by introduction of hydrogen chloride and aluminum oxide would be rendered insignificant by controlling surface water runoff from the firing pads, thereby eliminating infiltration. The FEIS also addressed ground shaking (under the topic of noise; FEIS Appendix F) and concluded that impacts would be negligible based on previous NASA testing experience. Additional review of potential impacts on groundwater quality is summarized below. Further literature review has also been conducted to analyze potential effects of ground shaking. Evaluations conducted for the SFEIS affirm that expected impacts of proposed ASRM testing will not cause any adverse impacts to groundwater quality or wells.

This section also discusses groundwater and well impacts, ground vibrations, and related effects to wells and aquifers, and presents conclusions.

GROUNDWATER AND WELLS

In order for ASRM testing to contaminate groundwater tapped by wells, three conditions would have to be met. First, ASRM testing would have to produce increased total acidity, destroying the natural "litter layer," or produce an aluminum form that would contaminate soil and/or surface water (Condition 1). Then, the contamination would have to migrate to and persist in the shallow, unconfined aquifer (Condition 2). Finally, water from this aquifer would have to move downward and mix with water in the deeper, confined aquifers (Condition 3). None of these necessary conditions will be met in ASRM testing, indicating that contamination of groundwater or groundwater wells is not projected.

Condition 1 is addressed in the sections on surface water and soils (Sections 4.2.2 and 4.2.4, respectively). Those discussions conclude that contamination of surface water and soil will not occur from ASRM testing. Thus, Condition 1 will not be met.

Condition 2 requires that potential contaminants migrate to and persist in shallow groundwater. Factors that protect groundwater quality are the buffering (neutralizing) and "filtering" capability of the soil through which recharging (inflowing) groundwater must pass, and the buffering capability and dilution capacity of existing groundwater with which recharging groundwater mixes (see below). With ASRM testing, the potential impacts to surface water and soil are increased acidity and increased aluminum concentrations. Because the groundwater is soft and possesses sufficient alkalinity (Newcome 1967) to buffer any increased acidity, the influx of hydrogen ions from any surface water carried to the groundwater will be neutralized. In addition, alkalinity of the soil below the water table would also buffer any increased acidity, thereby providing further stabilization of groundwater pH. In the case of aluminum, neutralizing the influence of low pH values through buffering would result in precipitation (separation of a chemical from the solution) of some or most additional aluminum. Soil can also filter dissolved aluminum through cation exchange and by combining (complexing) with organic acids (see Section 4.2.4). Because of dilution, precipitation, and adsorption to soil, no detectable increase in groundwater concentrations of aluminum is expected from ASRM testing. Thus, Condition 2 will not be met.

Condition 3 requires that potential contaminants migrate to water resources tapped by wells in the region. However, even if the ASRM testing were to adversely affect the shallow, unconfined aquifer, all deeper aquifers that supply water to drinking water wells would be protected due to the occurrence of two naturally occurring factors: the clay aquitards present between aquifers and the upward vertical component of the hydraulic gradient (the direction of the groundwater flow driving force). Sedimentary beds that underlie SSC consist of sand layers 25 to 150 feet thick that act as aquifers (sediments that permit easy water flow) separated by equally thick silt and clay layers that act as aquitards (sediments that restrict water flow). The aquitards separate the aquifers, which lie underground in alternating layers, resulting in very minimal flow between the distinct aquifers. Thus, water in the subsurface flows easily in horizontal directions, but has great difficulty flowing up or down through the clay layers.

The separation of aquifers created by the clay aquitards also allows maintenance of a difference in pressure between aquifers (termed "confined aquifers"). Increasing aquifer depths correlate with greater artesian pressure and higher hydrostatic heads (the elevation to which the water level in a well will come to rest). The vertical component of groundwater flow is therefore upward because the hydrostatic head increases with the depth of individual aquifers (Newcome 1967). This potential upward flow is blocked, however, by the aquitards. Because of the intervening clay aquitards and upward hydraulic gradient, water from the shallow, unconfined aquifer would not move downward to mix with the deeper, confined aquifer, and Condition 3 would not be met.

To determine which water resources require absolute protection, groundwater use for the SSC area was also examined. Water used in the region is delivered from numerous groundwater wells for agriculture or private and municipal water supplies, all of which are reported to tap water from deep below the surface (Newcome 1967; Colson and Boswell 1985). SSC has seven potable (drinking) water wells (completed to depths of 602, 652, 676,

688, 1,481, and 1,530 feet) and three industrial water wells (completed to depths of 672, 1,695, and 1,873 feet). No operational wells are present within at least 2,700 feet of the proposed ASRM test stand.

Potable water extends to a depth of approximately 3,000 feet on the west side of the SSC buffer zone and to approximately 2,000 feet on the east side (Newcome 1967). Numerous wells in the area tap the various aquifers at typical depths of 400 to 1,000 feet (Colson and Boswell 1985). Most of the deeper aquifers have artesian pressures sufficient to produce free-flowing wells at the surface (Newcome 1967; Colson and Boswell 1985). No wells at SSC tap the shallow, unconfined aquifer, nor is this aquifer used in the region (Newcome 1967; Colson and Boswell 1985). However, some private, shallow wells may exist between SSC and the Gulf to the southwest, and these wells may withdraw water from the unconfined aquifer.

Recharge (or the source of water) to the deep, confined aquifers used for water wells (400 to 1,800 feet deep at SSC) occurs tens of miles to the north-northeast where the gradually dipping (sloping) geologic units are near the ground surface. The shallow, unconfined aquifer in and around SSC at the depth of the water table is recharged from local sources (rainfall, rivers, lakes). Water at or near the surface in the SSC area does not move down to the depths tapped by deep wells due to the upward hydraulic gradient and the barriers formed by the clay aquitards.

In summary, ASRM testing would not result in any adverse impacts to groundwater quality or groundwater wells. None of the three conditions necessary to cause degradation of groundwater or groundwater wells would be applicable to ASRM testing. There would be no soil and/or surface water contamination; no migration of harmful substances to the shallow, unconfined aquifer; and no mixing of water from the unconfined aquifer with water in the deeper, confined aquifers. The wells that tap the confined aquifers would be protected by the absence of all three conditions, while any wells tapping the shallower aquifers would still be protected by failure to satisfy Conditions 1 and 2.

GROUND VIBRATION AND WELLS

Some ground vibration would be generated by ASRM testing at the test site. Because of the very small magnitude of ground vibration (hundredths to thousandths of an inch) that would be generated, ground motion from ASRM testing would have no effect on water wells in the area.

Test firing of the ASRM would generate some ground vibrations at the site transmitted through the test stand and through very minor vibrations transferred from the loud, low-pitched noise to the ground. The ground vibrations generated from the test are expected to be of small magnitude, based on measurements conducted during previous Saturn rocket tests at the site for the Apollo program and modeling of ASRM-generated ground vibrations (Ransford 1990). In the case of the Saturn tests, wells adjacent to the test stand were undisturbed. Each Saturn-1C stage generated approximately 7.5 million pounds of thrust, while ASRM testing would generate only 3.5 million pounds of thrust. Because the

ASRM test would produce a thrust that is less than half of the Saturn, the resulting ground vibrations from ASRM testing would be of smaller magnitude and would attenuate (lessen) over a shorter distance. Because of rapid attenuation of ground vibrations in the soft, saturated, native soils, the preliminary analysis predicts a worst-case wave amplitude (the distance that ground will move back and forth) of 1 mm at 1 kilometer (0.04 inches at 0.6 miles) from the test stand (Ransford 1990).

For purposes of comparison, studies were reviewed from seismic shothole blasts (underground dynamite explosions) for geophysical prospecting (Bond 1975) and quarry blasts (explosions for breaking or loosening rocks; Robertson et al. 1980; Robertson 1988). The blasts result in shock waves (mostly P-waves) that are the equivalent of small earthquakes (magnitudes of $M = 2$ to $M = 3$ on the Richter scale), but the studies show that these ground-vibration events do not affect nearby water wells. Preliminary analysis of ASRM testing indicates that ground vibrations would be less than or equivalent to vibrations generated during geophysical surveys and quarry blasts. This magnitude of ground vibration would not be felt outside the buffer zone.

The rare conditions under which groundwater wells may be damaged involve severe ground vibration and ground movement during a large magnitude earthquake (for example, a magnitude of $M = 6$ or above on the Richter scale) in areas of active earthquake faulting (such as along the San Andreas fault in California). Underground components of wells rarely are damaged by severe vibration alone, but damage may occur in areas near active faults that undergo significant shifting of the ground because of fault movement (Eguchi et al. 1981). Severe changes in hydraulic head (water levels) or in permeability of aquifers occasionally occurs in areas of active fault movement where bedrock undergoes strain or deformation by means of compression, expansion, or shearing (Wood et al. 1985).

Ground vibration from ASRM testing, therefore, is not projected to affect groundwater wells in the area because the magnitude of vibration will be extremely small and will dissipate over a short distance (probably within several hundred meters). This conclusion is supported further by the fact that previous test-stand firing of the Saturn rocket stages showed no effect on water wells, even those in the immediate test area. ASRM testing is not analogous to large-magnitude seismic events along earthquake faults.

CONCLUSIONS

ASRM testing will not impact groundwater quality or groundwater wells. Groundwater quality in the area should not be affected by ASRM testing due to buffering and natural treatment by native soil, buffering by alkalinity of the groundwater, and prevention of downward groundwater flow by the occurrence of an upward gradient and effective barriers formed by horizontal clay aquitards between aquifers. Even if deposited aluminum and low-pH water were to reach the uppermost, shallow aquifer, the aquifer would be protected by natural buffering and treatment capabilities of soil and groundwater, along with dilution by means of mixing with large groundwater volumes.

Ground motion generated by the testing would be of very small magnitude and would be reduced to negligible levels within several hundred meters of the test stand. Thus, the water quality and structural soundness of local drinking water wells would not be adversely affected by ASRM testing. This supports the findings of the FEIS and is based on more detailed analysis of the two areas of potential concern.

4.2.6 Wildlife and Domestic Animals

INTRODUCTION

The FEIS concluded that the effects of ASRM testing on wildlife would be minor. This conclusion was based on two primary factors. First, few, if any, animals would be killed by the force of the rocket exhaust. The safety zone around the test stand will be cleared of vegetation and therefore devoid of wildlife habitat, and human pretest activities will likely disperse any animals from the test stand area. Second, the concentration and duration of exposures of aluminum oxide and HCl are far below doses that cause measurable injury to animals. Additional air quality modeling, discussed in Section 4.2.1, has resulted in lower predicted air concentrations of aluminum oxide and HCl than those originally evaluated in the FEIS. The additional air quality analysis, coupled with water quality, soils and plant impact analyses presented in this SFEIS, support initial conclusions regarding impacts to wildlife from ASRM testing under expected conditions. The information supporting this conclusion is presented below.

There are several mechanisms through which air pollution from any source can affect animals: 1) animals can ingest, inhale, or be directly exposed to emissions in the air; 2) animals can ingest other organisms (plants, animals, or insects) that have accumulated substances from the air, water, or soil; and 3) animal habitat can be lost as a result of plant injury. For the ASRM project, the analysis is focused on the first mechanism. Since there is no known evidence of either HCl or aluminum oxide bioaccumulation in animals, impacts via the second mechanism (ingesting other animals or insects) are not expected. Similarly, adverse impacts to plants and soils have not been predicted (Section 4.2.4) so that ingestion of injured plants (the second mechanism) or loss of habitat from plant injury (the third mechanism) are not predicted under Case 1 conditions.

HCL AND ALUMINUM EFFECTS ON ANIMALS

Effects of HCl Inhalation

Land-based wildlife at SSC includes wild turkey, gray and fox squirrels, gray fox, raccoon, striped skunk, beaver, nutria, rabbits, quail, and deer. A complete list of animal species identified in the SSC area has been compiled by Esher and Bradshaw (1988) and was included in the FEIS. Of these animals, only rabbits have been used for laboratory tests involving HCl. Rabbits were found to have damage to their lungs when exposed to 49 mg/m³ of HCl gas for 10 minutes (NASA 1977). In another study, guinea pigs were found to have no lung damage from exposure to 15 mg/m³ of HCl gas for 2 hours per day, 5

days/week, after 18 days (EPA 1986). Guinea pigs exposed to hydrogen chloride at 0.15 mg/m³ for 2 hours/day, 5 days/week for 4 weeks did not show any effects (Kirsch and Drabke 1982).

From these studies, a threshold air concentration for injury to small animals breathing HCl could be estimated between 15 mg/m³ and 49 mg/m³. The air quality modeling results shown in Table 4-3 indicate the maximum predicted HCl concentration is 0.24 mg/m³, or approximately 100 times below this injury threshold range for HCl. Therefore, no adverse effects on animals are expected due to HCl inhalation.

Effects of Aluminum Oxide Inhalation and Deposition

In similar laboratory studies using aluminum oxide dust, rats and mice experienced eye and nose irritations at a concentration of 478 mg/m³ for 60 minutes (EPA 1987a). Air quality modeling results (Table 4-3) predict a maximum instantaneous concentration of aluminum oxide of about 0.4 mg/m³, or over a thousand times less than the irritation concentrations reported for rats and mice. Deposition of aluminum oxide onto the skin, fur, or feathers of animals will not cause injury because it is inert and will not be absorbed through the skin.

Effects of Aluminum Chloride

As shown in Table 4-3, deposition of aluminum chloride is predicted to be very low. While few studies have been conducted relating to the effects of dry aluminum chloride on terrestrial animals, many studies have been conducted using aqueous exposure of aluminum chloride on aquatic organisms. Aquatic organisms such as fish and amphibians (Section 4.2.3) are generally more sensitive to toxins than terrestrial animals. In summary, the deposition of aluminum chloride is expected to be approximately 40,000 times less than the minimum concentration causing 50 percent mortality in laboratory tests with toads. Because the concentration of aluminum chloride is so far below the level that would harm aquatic species, and because aquatic species are more sensitive than terrestrial species, no adverse effects on wildlife or domestic animals are expected due to aluminum chloride exposure.

Effects of Increased Acidity and Acid Rain

Of all groups of animals, amphibians and invertebrates are the most sensitive to direct exposure to increased acidity. Amphibians are discussed in Section 4.2.3, Aquatic Life. For other nonaquatic animals less sensitive than amphibians, such as wild mammals, birds, or livestock, there are no documented cases of exposure to acid rain which produced any significant injury (Haramis 1990). Only with extremely high laboratory doses of HCl (73,440 mg/l) has any injury to animals been documented (Vermot et al. 1977), and which are not found under Case 1 conditions.

CONCLUSIONS

Under expected conditions without rain, ASRM testing is expected to have no impacts on wildlife or domestic animals. Air concentrations of HCl produced by the ASRM are predicted to be 100 to 200 times below the injury threshold observed for small animals. Aluminum oxide predicted concentrations are 1,000 times less than irritation levels for small animals (rats or mice). Aluminum oxide deposited directly onto the skin, fur, or feathers of animals is not expected to cause injury since the deposition rate is well below the irritation level and because aluminum oxide is inert and will not be absorbed through the skin. Aluminum chloride depositions are 40,000 times less than those reported to cause injury to toads. Thus, no adverse impacts on wildlife or domestic animals is projected.

4.3 IMPACTS UNDER CASE 2 CONDITIONS

Under the Case 2 unexpected conditions, a significant rainfall event is presumed to occur one hour after the test firing. This case therefore depends on some failure of the weather forecasting system, so that the rain occurs unexpectedly.

4.3.1 Air Quality

INTRODUCTION

By using the dispersion results described in Section 4.1.2 in air quality impacts from ASRM testing were evaluated for the unexpected Case 2 conditions. The following sections discuss the modeling results and predicted impacts under Case 2 conditions. Discussions of chemical, physical, and biological principles were presented under Case 1.

Hydrogen Chloride

The ground-level HCl air concentrations predicted under Case 1 will also exist in Case 2 until rain begins. The ground-level HCl concentrations would be as described in Section 4.2.1 from the time of the test until one hour after the test.

The Case 2 scenario assumes that all of the HCl in the exhaust plume is incorporated into a rain cloud and rained out. The process by which the HCl becomes dissolved in the rainwater requires that the HCl first be dissolved in the tiny droplets of the cloud (Jensen 1984; Pruppacher 1980). Since the relative humidity in a buoyantly rising exhaust plume at cloud level will be very near 100 percent due to the additional water vapor produced during fuel combustion, the HCl will be dissolved in aqueous aerosols. During a rain event, the HCl aerosols would enter the rain cloud, allowing the formation of cloud droplets^{1/} on the aerosols. (Although many of the HCl aerosols may be too small to form cloud droplets initially, the Case 2 scenario conservatively assumes that all the HCl

^{1/} Cloud droplets are the tiny (5-10 μm diameter) droplets of water that make up a cloud. See Glossary.

aerosols will form cloud droplets.) The cloud droplets will then coalesce with each other until they have formed drops that are large enough to fall to the ground (i.e., raindrops). Each raindrop typically consists of about a million cloud droplets (Wallace and Hobbs 1977).

For the Case 2 scenario, all the HCl is assumed to rain out in 3/4-inch (2 centimeters) of rain over the area of the rain cloud (a typical medium-sized rain cloud area of 36 square miles was used for these calculations). A 3/4-inch rain was selected for analysis because smaller amounts of rain would rain out only a portion of the total HCl in the plume.^{1/}

When the HCl is added to the rainwater, it adds acidity^{2/} already present in the rain. The background rain acidity for Case 2 was calculated using the most recent five-year average background acidity, pH 4.5,^{3/} for southern Mississippi (USGS 1989). The background rainwater data from SSC show a range of weekly averaged rainwater pH values of 3.7 to 6.2. Since the measured rainwater pH values are weekly averages, single event background rain events may have pH values below 3.7. In general, rainwater in southern Mississippi is already quite acidic.

INPUFF 2.3 modeling of the exhaust plume indicated that the concentration of HCl in the rain will decrease as the plume disperses with time. If rain occurs one hour after the test, therefore, the acidity in the rain will be lower (slightly higher pH) than if it rains immediately after the test (Table 4-8) (see Appendix D).

The acid rain predictions based on the INPUFF 2.3 modeling are valid only for a short time (i.e., up to 2 hours after the test), because the meteorological conditions assumed in the modeling (unidirectional, steady, and low wind speeds) could not persist due to the changing wind and turbulence conditions associated with the warm, coastal environment at SSC (Hsu 1988). The wind and turbulence conditions at a coastal site such as SSC will change throughout the day. A typical time for these atmospheric changes is about 4 hours (Stull 1988). The changing wind directions and wind speeds, vertically and laterally, would increase the dispersion of the plume such that the HCl air concentrations would be extremely low. A rain event occurring three, four, or more hours after a test would show no increase in acidity due to HCl.

1/ Since the acidity depends on the percentage of HCl dissolved in the rain and this percentage may vary considerably depending upon the nature of the cloud, the acidity of the raindrops from a minor rain event incorporating an HCl exhaust plume is impossible to determine. Measurements from a minor rain during a Titan III launch at KSC showed a wide range of rain pH values within a six-mile radius of the launch site (Pellett et al. 1983).

2/ Background rainwater acidity is the result of natural sources of acidity plus existing man-made sources.

3/ pH is a measure of the acidity or alkalinity of an aqueous solution (such as rain). pH values below 7 are considered acid and pH values above 7 are considered alkaline. The relevance of pH values was discussed in Section 4.2.2, Surface Water.

Table 4-8. Case 2: Predicted Rainwater Acidity

Distance From Test Stand (miles)	Elapsed Time (min) ^{a/}	Total Rainfall (inches)	Concentration of HCl in Rainwater (m/l)	pH of Rainwater ^{b/}
0	0	0.75	56	2.8
4.5	60	0.75	46	2.9
9	120	0.75	39	3.0

a/ Distance and time are related to windspeed. At the modeled ground-level windspeed of 4.5 miles/hour, the plume would be over an area extending from about 3 to 7 miles from the test stand after 60 minutes, and would be over an area 8 to 12 miles from the test stand after 120 minutes.

b/ For sample calculations of rainwater acidity, see Appendix D.

Aluminum Oxide

Laboratory studies of the reactions between aluminum oxide and HCl suggest that the aluminum oxide particles in the solid rocket motor exhaust will acquire a soluble chloride coating (Cofer and Pellet 1978; Cofer 1978). The soluble chloride coating may allow the particles to act as cloud droplet condensation nuclei^{1/} and therefore allow the aluminum oxide particles to be removed by rain. Filter samples of solid rocket motor exhaust from Space Shuttle launches collected from an airplane a few minutes after the launch at an altitude of about 0.7 mile revealed almost no surface chloride coatings on the aluminum oxide particles (Cofer et al. 1987). However, in a later study, exhaust plume samples of a Space Shuttle launch collected at altitudes between 2.9 and 4.7 miles contained 0.6-1.0 percent chloriding by weight (Cofer et al. 1989). Although some chloriding may occur on the aluminum oxide particles, studies have shown that the concentration of ice nuclei^{2/} in the Space Shuttle plume remains similar to the natural background concentrations at KSC, indicating that the aluminum oxide particles (either coated with chlorides or not coated) do not form ice nuclei (Cofer et al. 1987).

^{1/} Cloud condensation nuclei are aerosol particles that allow enough water vapor to deposit on them to form a cloud droplet.

^{2/} Ice nuclei are aerosol particles that allow water vapor to freeze upon deposition to form crystals of ice. Ice nuclei are important in initiating rain from clouds (see Appendix E.).

Because of the small amount of soluble coatings on the aluminum oxide particles in the actual Space Shuttle exhaust samples and the lack of elevated levels of ice nuclei, it is clear that the aluminum oxide particles present in the exhaust do not readily form cloud droplets. This means that any aluminum oxide particles in ASRM exhaust would not be rained out in the time it takes the ASRM plume to completely dissipate. As in Case 1, most of the aluminum oxide in the ASRM exhaust will remain suspended in the air, and about 1.07 to 1.56 mg/m² will be deposited on the ground downwind of the test stand by dry deposition (Table 4-4). As the plume dissipates, all the particles produced in the exhaust plume will eventually be deposited in minute quantities spread out over a vast distance. The average time particles of this size remain suspended in the atmosphere is about two weeks (Pruppacher 1980). No negative impact or measurable increased contribution will exist after this period of time.

Aluminum Chlorides

If the HCl enters a cloud, much of it will dissolve into droplets of water. For those droplets that may have captured an aluminum oxide particle, aluminum chloride may be formed by Reaction 4-1. As discussed under Case 1, however, this reaction is not thermodynamically favored and is unlikely to occur. Therefore, no new aluminum chloride is expected to form in clouds or rain as a result of reactions between HCl, water, and aluminum oxide.

Some aluminum chloride is expected to form during the combustion process. If the plume enters a cloud, this aluminum chloride will readily dissolve in the droplets of water or will act as cloud condensation nuclei. Once dissolved in water, the aluminum chloride would be rapidly hydrated (Pierce 1970). The hydrated aluminum chloride would further react with water to form aluminum hydroxide [Al(H₂O)₃(OH)₃] which is a nontoxic, colorless, and amorphous compound (Pierce 1970). Under Case 2, therefore, the existing aluminum chloride would oxidize to a nontoxic aluminum hydroxide before being deposited on the ground by rain.

CONCLUSIONS

Additional air quality modeling using the PCAD and INPUFF 2.3 models indicates that HCl, aluminum oxide, and aluminum chloride produced by ASRM tests will occur in ground-level concentrations below state and federal air quality standards. This conclusion applies to both Case 1 and Case 2. Small amounts of both aluminum oxide and aluminum chloride will be deposited on the ground and other surfaces under both Case 1 and Case 2 conditions. HCl, however, would be deposited only under Case 2 conditions, when it would be dissolved in the raindrops falling to the ground. Additional topics, regarding the behavior of the exhaust plume in the humid environment of SSC and its ability to form a raining cumulus cloud, are addressed in Appendix E. Appendix E also contains a review of the meteorological principles governing the exhaust plume behavior and is pertinent to both the Case 1 and Case 2 discussions.

4.3.2 Surface Water

INTRODUCTION

Environmental water chemistry is complex, and many variables are associated with surface water characterization. In order to calculate the buffering capacity of the surface waters (defined as creeks, sloughs, bogs, marshes, and wetlands) and to quantify the amount of acidic input potentially resulting from test firing the ASRM, limits were placed on the number of variables investigated. Those variables that would be expected to have the most significant impacts on surface water characterization were fully investigated, and include pH, alkalinity, and water volume. Other variables, which play a less critical role in surface water characterization, were not utilized in calculations. These other variables include runoff volume, surface water flow, and variability in rainfall pattern within the rainfall area. Additionally, the buffering capacity of hydric soils was not taken into account, even though these soils can help neutralize acid (Section 4.2.4). In summary, only the most critical factors affecting surface water buffering capacity were utilized for calculation purposes.

Existing surface water quality is compared to the estimated additional inputs from ASRM testing in Table 4-9. Four values were used as representative surface waters: 1) the average (geometric mean) of all the sampled sites at SSC; 2) the East Pearl River sample; 3) the Red Fish Hatchery sample; and 4) the northern branch of Devil's Swamp sample.

In Case 2, firing takes place under unexpected conditions which would result in 100 percent of the HCl present in the exhaust being rained down onto land and surface waters. The location of this acid fallout would depend upon wind speed, wind direction, and so forth, as discussed in Section 4.2.1. The concentration of this fallout would be a function of the plume's dispersion.

Under Case 2 conditions, the pH of rainwater would drop from an average value of 4.5 to 2.9, as discussed in Section 4.2.1. The method for calculating this pH drop is shown in Appendix D. Rainwater of pH 2.9 falling on surface waters with sufficient buffering capacity would be expected to cause no measurable change in the acidity of the water, while the same rainwater falling on water with insufficient buffering capacity would be expected to cause a temporary increase in acidity of those surface waters. The degree and duration of the resulting increased acidity would depend on the several variables mentioned earlier, including surface water volume, alkalinity, pH, and the volume of rainfall.

Table 4-9 indicates the changes in acidity, as expressed by the pH changes, for the four water samples mentioned above. The pH of the vast majority of surface waters in the vicinity of SSC would not be affected. The pH of these waters (as "average" surface water) would not be expected to decrease from 6.1, due to sufficient buffering capability (alkalinity = 24.7 units) (Appendix C). Similarly, sufficient buffering capacity exists with the groundwater supply to Red Fish Hatchery (alkalinity = 166 units, Table 4-6) to neutralize

Table 4-9. Case 2: Estimated effects of acid rain deposition from ASRM testing on surface water pH, Stennis Space Center, Mississippi.

	pH of Rain and Surface Waters	
	Background	Predicted Under Case 2 Conditions
Rain	4.5	2.9
Average (Geometric Mean) Surface Water	6.1	6.1
East Pearl River	6.3	6.3
Red Fish Hatchery	5.4	5.4
Northern branch of Devil's Swamp	5.8	4.2

the amount of acid input that could be expected from ASRM testing under Case 2 conditions.

An alkalinity value of 12 units was measured in the East Pearl River sample. The pH of this sample was 6.3. Waters with a measured alkalinity of 12 units have the capacity to neutralize 0.00024 unit of hydrogen ion. Only 0.0000005 unit of hydrogen ion/l is present at pH 6.3. Therefore, results of these calculations indicate that waters with the pH and alkalinity of the East Pearl River sample are adequately protected from any acidic input that would take place from ASRM testing even under Case 2 conditions.

As seen in Table 4-9, the only reduction or impact to surface water is for the northern branch of Devil's Swamp. Because of the low buffering capacity of this water body, the temporary, short-term addition of acidic rain water would result in a temporary, localized increase in acidity to pH 4.2. This was the only water sample that showed a measurable increase in acidity, and it is representative of the estimated effects on similar shallow, low flow, low alkaline water bodies.

The estimates given in Table 4-9 are conservative. They may overestimate the change in pH because it assumes direct contact of rain water with surface water without any hydric soil buffering. The increase in acidity would not be expected to remain, but would return to background levels in a time period conservatively estimated at less than 1 week. Rapid recovery is expected due to the replenishment of alkalinity from the underlying sediments and soils. To summarize, the natural balance of the receiving waters would not be expected to experience any long-term change due to the addition of predicted acid levels under Case 2 conditions.

These estimates were calculated from the best available data. Single point measurements are insufficient to draw definitive conclusions on any water body; but collectively, they provide a moment in time "snapshot" of existing conditions at the eight sampled sites. Because the pH values of the eight sampled sites fall within the same general range of pH values found through several years of water quality monitoring in and around SSC, the results described here are believed to be representative of local surface waters.

Comparison of Existing and Predicted Conditions: Hydrogen Ion

Comparison between existing conditions (pH and alkalinity) and predicted conditions indicate that under situations that are most likely to occur (i.e., Case 1 conditions), no acid fallout is expected from ASRM testing and there would be no impact to surface waters. Under Case 2 conditions, there could be temporary, localized effects resulting from acid rain on selected, small, shallow surface waters with low water volumes, low alkalinities, and restricted water exchange rates. The net result of this evaluation is that the combination of surface water neutralizing capacity and relatively small additions of acid even under Case 2 conditions would not result in further acidification of surface waters.

Predicted Conditions: Aluminum

The analysis of aluminum deposition from ASRM testing considered all known toxic species of aluminum and all potentially toxic or water soluble species of aluminum. The deposition of aluminum oxide due to test firing the ASRM, modeled under Case 2 conditions, led to a predicted deposition of aluminum oxide equal to approximately 1.07 to 1.56 mg/m² (Table 4-4). This is the same as results for modeling under Case 1 with the effect on surface water being the same.

CONCLUSION

Under Case 2 conditions, where rain would be present soon after test firing the ASRM, acid depositions to surface waters would not result in any impacts to larger surface water bodies at SSC. The natural conditions of the larger surface water bodies at SSC would remain unaffected due to the relatively low acid input and relatively high natural buffering capacity. The bodies of water that are small, shallow, and naturally low in alkalinity may experience a temporary increase in acidity that would be expected to return to natural conditions within a time period conservatively estimated at less than one week.

Case 2 aluminum depositions are the same as those predicted for Case 1. Therefore, conclusions stated in Section 4.2.2 remain the same for aluminum.

COMPLIANCE WITH MISSISSIPPI AND FEDERAL WATER QUALITY CRITERIA

The water quality analysis presented above supports the original conclusion in the FEIS that no significant water quality impacts are anticipated from ASRM testing at SSC. As stated in the FEIS, NASA is committed to complying with federal and state water quality criteria and guidelines covering effluent discharges and receiving waters.

The Mississippi criterion for pH is equivalent to or more stringent than the federal water quality criterion. The Mississippi water quality criterion for pH requires that the normal pH of receiving waters may not be changed more than 1.0 unit. Under Case 1 conditions, no change in pH is predicted, thereby complying with the Mississippi criterion for pH. Under Case 2 conditions, however, temporary pH change (greater than 1.0) is predicted for isolated shallow, low flow, low alkaline waters. Even these waters are projected to regain their natural acidic balance in less than a week. Thus, only under the unexpected conditions and for a few water bodies would testing potentially violate the Mississippi water quality criterion.

There are no specific Mississippi criteria for aluminum, but general Mississippi receiving water quality criteria state that no toxic substances are allowed that will impair the use of waters. Since no impairment is expected, this criterion is met.

4.3.3 Aquatic Life

INTRODUCTION

If it were to rain shortly after testing (Case 2), the pH in the northern branch of Devil's Swamp, and in water with similar characteristics, may be reduced from 5.8 to 4.2. The aluminum concentrations in surface waters are predicted to increase by trace amounts (less than 0.0060 mg/l) following testing, with or without immediate rainfall. The predicted deposition of aluminum chloride associated with ASRM testing corresponds to an aluminum chloride (AlCl_3) concentration in shallow surface waters (6 inches or less) of less than 0.000005 mg AlCl_3 /l (approximately 0.000001 mg Al/l). Regardless of the degree of bioavailability of the aluminum currently present in the region's smaller drainage areas, many of these water bodies are not expected to support fish because they are too shallow or are intermittent; that is, they dry up during part of each year. These intermittent water bodies may support other aquatic organisms, such as invertebrates and amphibian larvae.

Under the unexpected conditions, no change in pH and only trace changes in aluminum concentrations are predicted except in drainages similar to the northern branch of Devil's Swamp, where a temporary increase in acidity is projected. The increased acidity in the northern branch and any similar small drainages could potentially have localized effects on aquatic populations. However, available information indicates that existing pH and aluminum levels in the small drainage areas where increased acidity is predicted may already be nonconductive to most, if not all, aquatic species. Except for the small drainage areas, more than sufficient buffering capacity exists at the other water bodies in the vicinity of SSC. No impacts are expected at the Red Fish Hatchery. Sufficient buffering capacity exists even under Case 2 conditions. The rainfall would cause no change in the pH of the hatchery's water source.

CONCLUSIONS

Should rain occur soon after testing, possible impacts may occur in some small drainages which have little buffering capacity. These areas may not currently be supporting aquatic life.

4.3.4 Plants and Soils

POTENTIAL ACUTE EFFECTS OF HCL DEPOSITION ON PLANTS

Most of the research concerning acid rain effects on vegetation document chronic effects resulting from acid buildup in soils, not acute effects of acid rain striking leaves, needles, and other exposed plant parts. In laboratory experiments, however, rain acidified with hydrochloric acid has been shown to produce lesions and bleaching in leaves, with the degree of damage depending on the plant species, duration of exposure, and concentration of hydrochloric acid (Jacobson and Hill 1970). Acid deposition on leaves may also prematurely remove nutrients from leaves via ion exchange and leaching (Reuss and Johnson 1986). One case of acute damage from acid rain associated with solid rocket motor

testing has been documented in Dade County, Florida. In this case, which occurred in 1967, Aerojet General tested a solid rocket motor while it was raining (NASA 1978). The resulting acid fallout damaged citrus crops in the vicinity.

Acute damage to plants can be caused by acid rain, and the degree of damage is determined by the degree of acidity in the rain and the sensitivity of the plant species. Plant species vary widely in their tolerance of acid deposition, with many species being highly sensitive and some species being highly tolerant. No research was identified that documents the sensitivity of various tree species to acute damage from acid rain. However, recent research by DuBoy and others (in press) and summarized by Kaplan (1989) described the relative tolerance of 216 varieties of 18 crop plants to simulated acid deposition that was more acidic (pH 2.5) than that predicted under Case 2 conditions (pH 2.9). DuBoy and his colleagues found that a 1-hour exposure to a simulated acid rain of pH 2.5 affected only the most sensitive species (including soybeans). In these sensitive species, the growth rate was reduced and leaves developed small bleached or burned spots, with damage varying from 5 to 24 percent of the leaf area. Highly tolerant species (including winter wheat, alfalfa, and corn) showed less than 2 percent damage to leaf area and did not exhibit a reduced growth rate. The most significant conclusion drawn by the researchers was that pollution danger to crops is more likely to be from sources other than acid rain, such as from ozone and ultraviolet radiation. On the basis of this research, it appears that testing under unexpected conditions should not result in any impacts except to the most sensitive species. Impacts could include spotting on soybeans and other sensitive plants exposed to acid rain. However, NASA is committed not to test when rain is predicted within 24 hours, depending on wind speeds.

As described earlier, Case 2 conditions indicate that a 0.75-inch rainfall one hour after a test would have a pH of 2.9. The acid deposition that would result even under these Case 2 conditions is not enough to change either the soil pH, the mineralogical characteristics of the soil, or the soil fertility (Adams 1990).

The acid in 0.75 inches of acid rain at pH 2.9 would require about 12 lbs of lime (as limestone, CaCO_3) per acre to neutralize. Local farmers typically apply a ton of lime approximately once every four years to each acre of soybeans (Baylis 1990). Thus, the additional effect of the Case 2 rainout of HCl totals only about 0.6 percent of the liming needs of typical agricultural practice in the area, indicating that any incremental acid contribution would be effectively neutralized.

CONCLUSIONS

Case 2 analyses for impacts to plants conclude that some leaf spotting from HCl exposure could occur to the most sensitive species only if a test firing were conducted during or shortly before rain. Similarly, Case 2 analyses for impacts to soils demonstrated that the quantity of HCl that may rain out is less than the natural acidity level of the soils which is dealt with by the local agricultural practice of applying lime. Given the best available information on amounts and deposition of emission products, soil buffering capacity, and

effects of acid rain on plants and soils, it is apparent that ASRM testing will not result in any long-term impacts to plants or soil, even for the Case 2 scenario.

4.3.5 Groundwater

No additional impact will result for the Case 2 scenario than that described in Section 4.2.5 for the Case 1 scenario.

4.3.6 Wildlife and Domestic Animals

Waterfowl need calcium (especially during breeding season for egg formation) that they commonly get from eating snails. Case 2 conditions were reviewed to determine if waterfowl could be indirectly affected by ASRM test emissions through reduced food supplies (such as, if snails would be adversely affected by the increased acidity predicted for localized shallow, low alkaline waters). The evaluation indicated that no impacts are expected to occur. For reduced food supplies to be injurious to waterfowl, increased acidity in surface waters would need to occur over very large areas so that snails, their primary food supply, would be affected over a large area. As discussed in Section 4.3 under Case 2 conditions, a short-term increased acidity is predicted only in localized water bodies and not over the majority of waters at or near SSC. Because no widespread effect on surface water acidity is predicted, no widespread effect on food supplies and therefore no effect on waterfowl is expected.

The Pearl River Delta (nine miles south of SSC) and the Pearl River State Wildlife Management Area (4 miles west of SSC) are very important to migratory shorebirds, especially in the spring (late March to late May) and fall (early September to early November) (Jackson 1990). No impacts from increases in acidity are projected for the animals inhabiting these areas due to the large size of the water bodies present and the buffering capacity of these waters.

CONCLUSIONS

If rain were to occur shortly after testing, the increase in acidity in small drainages potentially could have localized effects on amphibian (tadpoles, snails, etc.) populations as discussed in Section 4.3.3. No adverse effect of acid rain on terrestrial animals is predicted.

4.4 CUMULATIVE EFFECTS

INTRODUCTION

The long-term effects of ASRM testing were analyzed to address the possible accumulation of deposited aluminum oxide and aluminum chlorides (particulate matter). Water quality certification under Section 401 of the Clean Water Act also requires information on cumulative effects.

The repeated release of HCl into the atmosphere will contribute a small fraction to the existing emissions of acid gases from the region (southern states). Long-term HCl impacts have therefore been addressed in the context of regional acid gas emissions and regional acid deposition patterns. Repeated testing of the ASRM over the projected 30-year life of the program will also result in the distribution of deposited particulate matter over a wide area on and around SSC. The issues addressed here concerning aluminum oxide and aluminum chloride deposition include: 1) quantification of total material deposited on and around SSC over 30 years of testing, 2) the fate of the deposited aluminum oxide and aluminum chlorides, and 3) possible environmental effects from long-term deposition.

Cumulative HCl Impacts

The air quality impacts due to an ASRM test were analyzed in Section 4.2.1. The analysis concluded that the deposition of HCl on and around SSC (within 12 miles of the test stand) as well as all other areas offsite would be negligible. Although the ASRM tests are not expected to increase the acid deposition near SSC, the HCl from ASRM testing will make a very small contribution to the total emissions of acid gases (mainly SO₂, NO₂, and HCl) from the region around southern Mississippi. Since the regional acid deposition pattern is primarily a result of the regional emissions of acid gases, the ASRM tests may contribute a small amount to this deposition pattern.

The annual emissions of SO₂ and NO₂ from all sources (industrial and private) in the southern states around Mississippi (including Alabama, Georgia, Florida, Kentucky, North Carolina, South Carolina, and Tennessee) have been estimated by the National Acid Precipitation Assessment Program (NAPAP 1990).^{1/} Additionally, the annual air emissions of HCl from all sources in the same southeast region of the United States have been estimated by EPA (EPA 1985). Table 4-10 presents these emission rates together with the predicted annual emissions of HCl from ASRM testing (assuming four tests per year). The HCl from ASRM testing will only constitute about 0.05 percent (that is, 5/100ths of a percent) of the acid gas emissions that contribute to the acid deposition in the southeastern United States.

The distribution of acid rain on the continental United States is determined by the large-scale (continental) atmospheric motions and the strengths of the sources of acid gases. The average acid rain distribution pattern in the southeastern United States (Figure 4-6) is primarily the result of the sources in that region. The HCl from the ASRM tests, therefore, will only add a slight contribution to this general deposition pattern.

^{1/} The NAPAP 1990 study organized emission information into geographical regions. Regional emissions which can best be compared to ASRM emissions include emissions from the states listed above.

Table 4-10. Annual emission rates of acid gases from southeastern states^{a/} of the United States.

Compound	Annual Emission Rate (tons/year)
Regional SO ₂ ^{b/}	5,300,000
Regional NO _x ^{b/}	3,700,000
Regional HCl ^{b/}	151,000
ASRM HCl	508

^{a/} Southeastern states include Mississippi, Alabama, Georgia, Florida, Kentucky, North Carolina, South Carolina, and Tennessee.

^{b/} Source: NAPAP 1990

Aluminum Oxide and Aluminum Chloride Depositions

The distribution of exhaust product deposition was modeled based on the frequency with which the wind blows in any one direction. The frequency distribution of wind direction is generally depicted by a wind rose. The annual wind rose for SSC for winds at about 10,000 feet aloft (NASA 1990c) was used to estimate the cumulative depositions from the ASRM program. These upper-level wind directions were chosen because they best represent the directions the exhaust plume will follow.

The cumulative 30-year depositions of aluminum oxide and aluminum chlorides were estimated by using the wind rose described above and the deposition data presented in Table 4-4. In order to remain conservative, the same upper-level wind speeds were assumed for all test firings and testing was assumed to occur four times every year for 30 years (120 total tests). The total amounts of deposited aluminum oxide or aluminum chlorides were calculated from the depositions at each of the five distances given in Table 4-4, multiplied by 120 tests. The cumulative deposition distribution was estimated by multiplying the total deposition at each of five downwind distances by the percentage frequency the wind blows in a particular direction.

The cumulative deposition distributions in Figure 4-7 indicate that most of the deposition will occur to the east of the test stand. The deposition map for aluminum oxide (Figure 4-7) shows a maximum isopleth of 18 mg/m² approximately 6 miles east of the test stand.

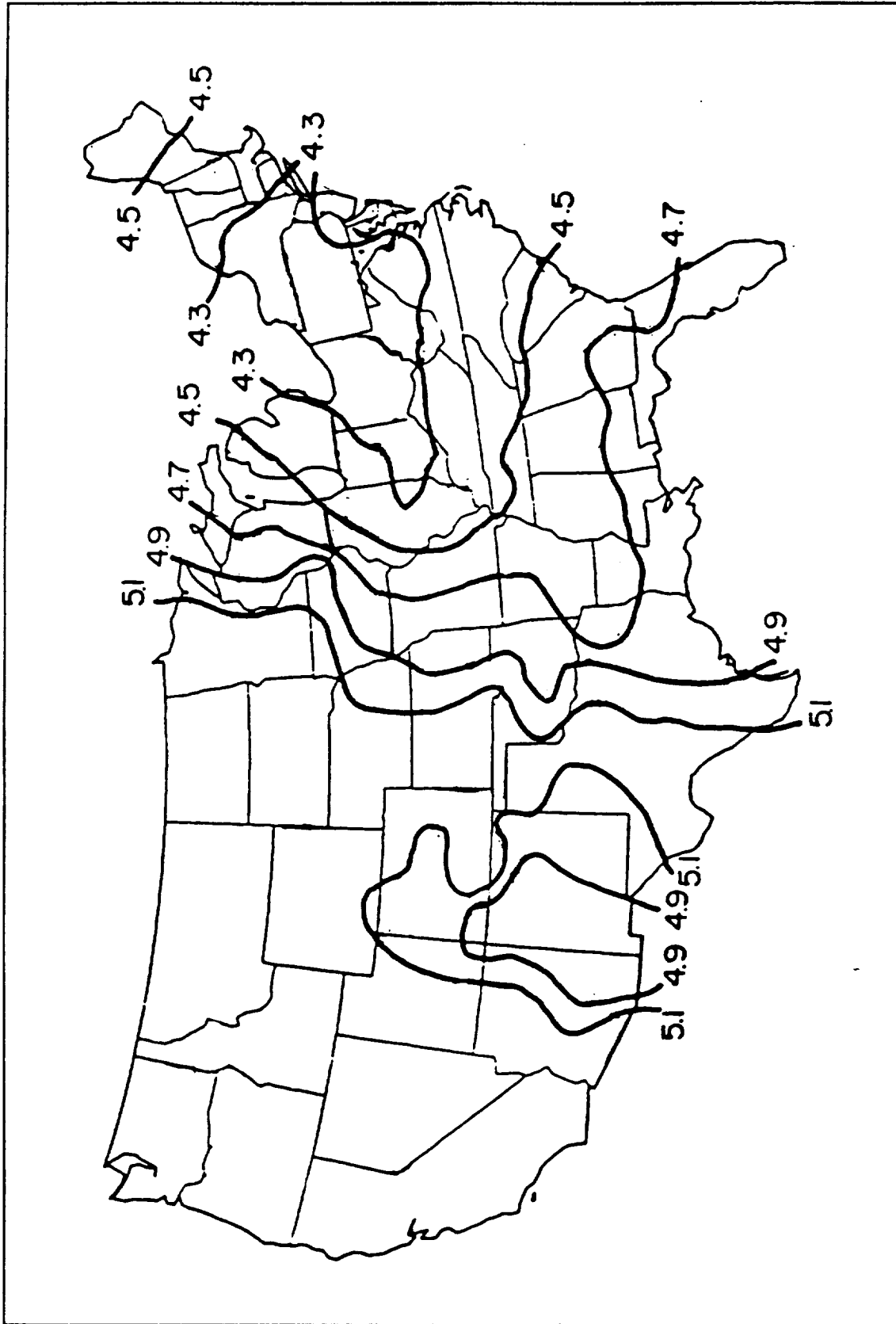
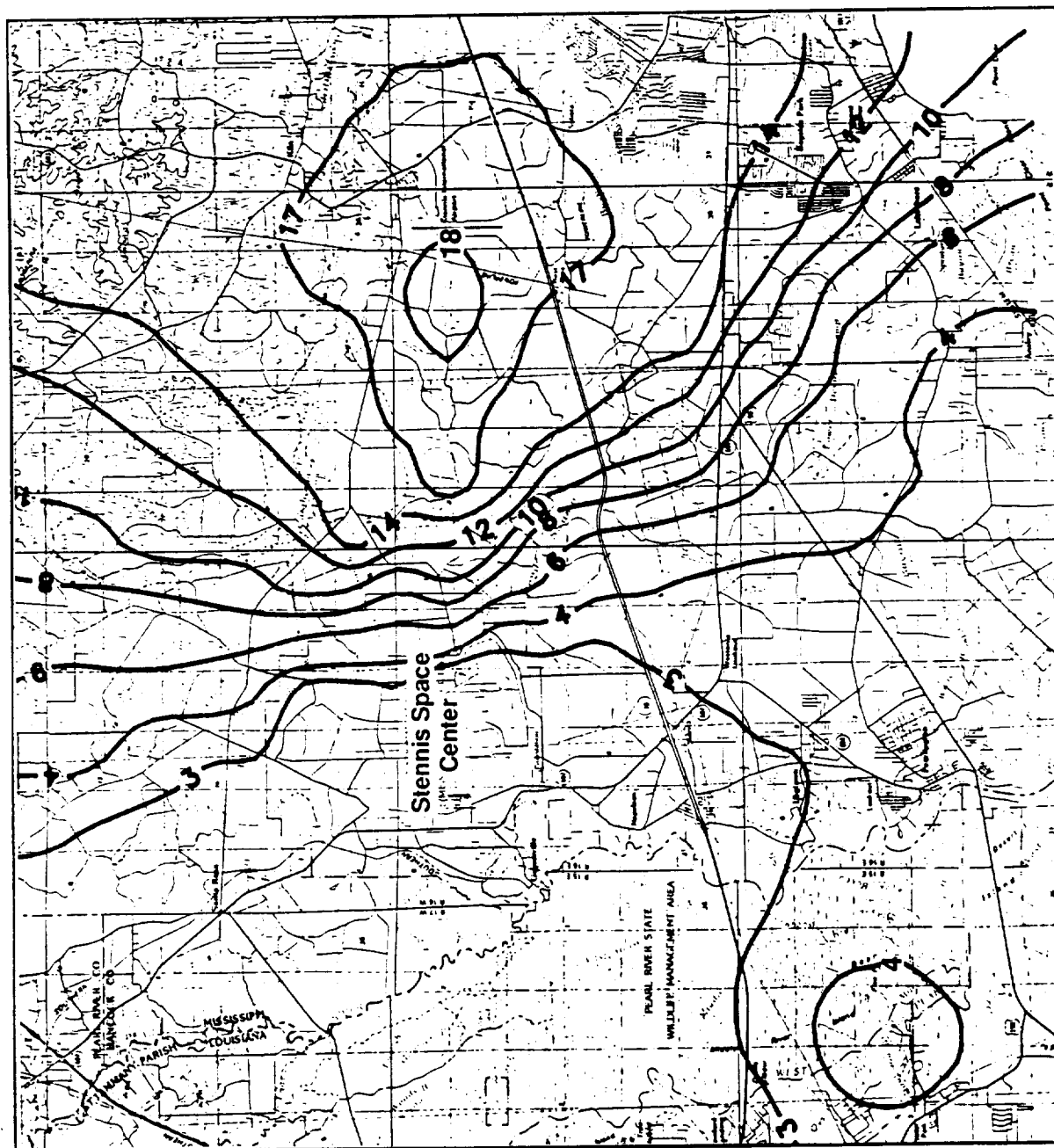


Figure 4-6. Annual Average Rain pH Distribution Pattern, 1988
(Source: NADP, 1988)



1 ¹/₁₀ inch = 3 miles

Figure 4-7. Thirty-year cumulative Aluminum Oxide deposition on map. Depositions are in milligrams per square meter.

Cumulative depositions at Slidell and Picayune, however, are only about 4.2 mg/m² over 30 years. The deposition pattern for aluminum chlorides is similar to that for aluminum oxide; however, the total depositions are 0.014 percent smaller.

As discussed below, the soils and surface waters will neutralize, transform, and remove most of the deposited material from each test more rapidly than the material will build up due to successive tests. The deposition map (Figure 4-7) therefore shows the total amount of material deposited over 30 years but does not represent a buildup of material. Cumulative effects of ASRM depositions are discussed below for plants and soils, surface water and aquatic life, and groundwater.

CUMULATIVE EFFECTS ON PLANTS AND SOILS

No long-term effect on plants and soils is expected even with 30 years of testing. As noted in Section 4.2.4, aluminum is immobilized by organic acids in the soils. The maximum deposition of aluminum oxide per test (1.56 mg/m²) is equal to only 0.0078 pound per acre, compared to the existing surface layer aluminum of 900 pounds per acre. The cumulative effect of 120 tests over 30 years would be far too small to affect the natural balance of the soils.

Given the buffering capacity of local soils, soil chemistry is not expected to change and soil fertility will not decline due to additions of acid. Reuss and Johnson (1986) have estimated that, for acid soils, soil chemistry (proportion of different nutrients, aluminum, etc.) would begin to change only under heavy and constant (year round) acid deposition over decades. At most, ASRM testing will occur only four times per year, not year round, and the incremental addition of acid to the soil would be extremely small. Therefore ASRM testing will likely have no effect on soil chemistry even after 30 years of testing.

Cumulative Effects on Surface Water and Aquatic Life

Even if all aluminum compounds were assumed to be potentially toxic, conclusions reached in Section 4.2.2 indicate that aluminum entering surface waters in and around SSC would be bound by organic acids in the water. Although some of the water samples indicate existing aluminum concentrations that exceed EPA criteria for protecting fish, it is also clear that other mechanisms are at work that allow even sensitive fish species such as striped bass to live in these waters. The additional aluminum loading associated with 30 years of ASRM testing operations would add negligible amounts of aluminum to this system.

Cumulative Effects on Groundwater

Groundwater quality will be protected over the long term through the same features at work in the short term. As noted in Section 4.3, these features include the buffering capabilities of the soil, surface water, and groundwater; the clay aquitards that restrict flow between aquifers; and the upward hydraulic gradient that directs groundwater flow upward rather than downward. All of these features will work to prevent any contamination in the groundwater. Thus, no cumulative impacts will occur.

5.0 HUMAN HEALTH EFFECTS

5.1 INTRODUCTION

Combustion of solid propellant during static testing will release large quantities of hydrogen chloride and aluminum oxide. Other principal constituents of the rocket exhaust include carbon monoxide, aluminum chloride, nitrogen oxides, and chlorine gas (see Section 4.2.2 for estimated emission rates). None of these constituents has been demonstrated to cause, or are even suspected of causing cancer or reproductive and developmental effects in humans or animals.

A typical human health risk assessment estimates contaminant exposure concentrations, determines who is or may be exposed, estimates contaminant intakes (doses) on a daily basis for different exposure pathways, determines the appropriate toxicity values (i.e., EPA reference doses and cancer potency factors), and characterizes the potential for adverse health effects (both cancer and noncancer) to occur. This methodology, especially the calculation of exposure doses, was not considered appropriate in the assessment of ASRM emissions because none of the contaminants is known to have long-term cancerous effects. More importantly, the exposures will occur only for a period of ten minutes to two hours at most, and only up to four times per year. Estimation of daily doses is not applicable to this sporadic exposure scenario since these contaminants are readily eliminated from the body and their potential effects are rapidly reversible. Therefore, the approach used for this human health evaluation was to compare predicted contaminant air concentrations from ASRM testing to the most appropriate federal and state standards and guidelines.

The following sections discuss the human health effects of exposure to ASRM exhaust constituents. Since the predominant exposure pathway for exhaust constituents is inhalation, the analyses focus on Case 1 conditions which are predicted to produce airborne concentrations of HCl, aluminum oxide, and aluminum chloride. No probable exposure pathway was identified for Case 2 (acid rain), because raindrops are too large to be inhaled. Therefore, the airborne concentrations and chemical fate of exhaust plume constituents used in these analyses are as described in Section 4.2.2. These exposure conditions are summarized in Section 5.2. The potential short-term and long-term health effects of HCl, acid aerosols, and aluminum oxide are discussed in Section 5.3. Included in Section 5.3 are current research observations and theories regarding the development of Alzheimer's disease, with emphasis on the association of human exposure to aluminum. Section 5.4 presents the summary and conclusions regarding human health effects, and Section 5.5 introduces members of a consultant panel of recognized medical researchers who reviewed the draft Section 5.0 for technical accuracy and completeness. Appendix F contains a detailed literature review of the relevant theories regarding the development of Alzheimer's disease, with particular emphasis on the role of aluminum. Finally, Section 5.6 discusses public and employee health and safety as they pertain to air emissions caused by the unlikely event of a case-rupture during static testing.

5.2 PREDICTED EXPOSURE CONDITIONS

As discussed in Section 4.2.2, ASRM test firings under Case 1 will release a hot plume containing primarily HCl and aluminum oxide, which will travel horizontally several hundred feet prior to rising into the atmosphere to a centerline altitude of about 13,000 feet. When the plume reaches its maximum altitude, it will have lateral and vertical dimensions of several miles as it moves downwind. Ground-level concentrations at any one point will last for ten minutes to two hours depending on wind speed. Since gaseous HCl is hygroscopic (readily dissolves in water), much of the emitted HCl will be found as an aqueous aerosol when the relative humidity is near 100 percent. Aluminum oxide is a relatively stable compound that is insoluble in water and weak acids. As stated earlier, one of the major human health concerns is potential conversion of emitted aluminum oxide to aluminum chloride in the presence of water and HCl. However, as discussed previously in this report, the formation of aluminum chloride is not thermodynamically favored. In fact, it is likely that most, if not all, of the aluminum chloride that is emitted in the exhaust will actually be converted to aluminum oxide or aluminum hydroxide in the exhaust plume as the plume cools and mixes with the air.

The air quality dispersion modeling predicts that the point of maximum instantaneous air concentration of HCl, aluminum oxide, and aluminum chloride would occur approximately 0.6 mile from the rocket test stand, and the maximum 24-hour average concentration would occur approximately 4.2 miles from the test stand (see Section 4.2.2). Maximum HCl, aluminum oxide, and aluminum chloride concentrations at the 0.6-mile distance were computed to be 0.24, 0.40, and 0.000059 mg/m³, respectively (Table 5-1). Maximum and time-weighted average concentrations of HCl, aluminum oxide and aluminum chloride at 3, 4.2, 6, and 12 miles from the test stand are also presented in Table 5-1.

The distance from the test firing stand to the boundary of the buffer zone ranges from approximately 6 to 9 miles. The nearest cities, including Pearlington, Picayune, Slidell, Bay St. Louis, Pass Christian, and Long Beach, are located within 6 to 18 miles from the rocket test stand. ASRM workers not directly associated with each test are located at least 2 miles from the test stand, as are other employees at SSC. ASRM workers will be removed to safe distances or into protective buildings prior to and during each test firing.

5.3 TOXICITY AND EXPOSURE ASSESSMENT

The following sections address toxicological and exposure issues associated with HCl, HCl aerosols, aluminum oxide, and aluminum oxide/HCl/water mixtures.

Table 5-1. Comparison of ground-level hydrogen chloride (HCl), aluminum oxide (Al₂O₃), and aluminum chloride (AlCl₃) concentrations from ASRM static testing

Compound	Maximum Averaging Time	Distance from Test Stand, Concentration in mg/m ³ ^{a/}				Applicable Health and Safety Standards and Guidelines (mg/m ³)
		0.6 mi	3 mi	4.2 mi	6 mi	12 mi
Hydrogen Chloride	Maximum	0.24	0.23	0.22	0.21	0.19
	1 hr	0.11	0.15	0.15	0.15	0.14
	24 hrs	0.0060	0.0087	0.0088	0.0087	0.0083
Aluminum Oxide	Maximum	0.40	0.39	0.38	0.36	0.33
	1 hr	0.19	0.26	0.26	0.25	0.24
	24 hrs	0.010	0.015	0.015	0.015	0.013
Aluminum Chloride ^{l/}	Maximum	0.000059	0.000057	0.000055	0.000054	0.000049
	1 hr	0.000028	0.000038	0.000038	0.000037	0.000035
	24 hrs	0.0000015	0.0000022	0.0000022	0.0000022	0.0000020

^{a/} Averaged values were calculated by using the highest averaged concentration over the given time period (see footnote Figure 4-3).

^{b/} OSHA 1989. Maximum occupational exposure (ceiling) limit which should not be exceeded at any time.

^{c/} NRC 1987. Recommended short-term public emergency guidance levels for 1-hour and 24-hour average community exposures during space shuttle launches.

^{d/} Mississippi Bureau of Pollution Control (MBPC) Regulation APC-S-1, Section 5.2.

^{e/} OSHA 1989. 8-hour time weighted average occupational standard.

^{l/} Aluminum chloride is compared to HCl standards since no standards exist for AlCl₃ and they have similar irritant toxic properties.

5.3.1 Potential Human Health Effects of HCl

SHORT-TERM HEALTH EFFECTS

Toxicological Considerations. HCl is highly water soluble and reacts with surface components of the upper respiratory tract. The hydrogen ion and chloride ion are natural constituents of near coastal atmospheres (Finlayson-Pitts and Pitts 1986) as well as all mammalian species. Two important chemical defenses against inhaled acidic compounds include endogenous (naturally occurring in the body) ammonia and airway surface liquid buffers (i.e., mucous) (EPA 1988b). Naturally occurring ammonia present on the surface of the nasal tract and mouth may react and neutralize (i.e., have a scrubbing effect on) low levels of acidic compounds such as HCl (Larson et al. 1982; EPA 1988b).

If HCl concentrations are quite high, such that they overwhelm the "scrubbing" capacity of the upper respiratory tract, then HCl may be deposited in the lower respiratory tract where it may cause acute irritation of the respiratory tract. This type of reaction only occurs at concentrations at least 100 times higher than those that would be observed at SSC. For example, Henderson and Haggard (1943) reported lower throat irritation in humans after a short exposure to 52 mg/m³ HCl, while no adverse effects were observed from prolonged exposure to 15 mg/m³. Further, rats exposed to 15 mg/m³ HCl for a lifetime did not experience any serious irritating effects to the nasal and pulmonary epithelium (Sellakumar et al. 1985). In addition, it appears that rodent species are an inadequate model for evaluating the toxicity of irritant gases in humans, in part because the rat is primarily a nose breather, unlike monkeys and humans which breathe through both the nose and the mouth. Based on anatomical comparisons, the baboon has the greatest upper airway similarity to children (Kaplan et al. 1988). Kaplan et al. (1988) reported no adverse short-term or long-term effects on pulmonary functions in anesthetized baboons exposed to HCl at exceptionally high concentrations (735 to 14,723 mg/m³) for 15 minutes. The predicted ASRM-related concentrations of HCl at 0.6 mile from the testing site (0.24 mg/m³, Table 5-1) are well below the "no-observed-adverse-effect-level" NOAEL observed in baboons (735 to 14,723 mg/m³) as well as the NOAEL for humans of 15 mg/m³ (Henderson and Haggard 1943). Therefore, based on the low expected concentrations from ASRM testing and natural neutralizing capacity of the oral-nasal passages, no acute or chronic respiratory effects or systemic effects of HCl are expected. Since the maximum instantaneous air concentrations decrease with distance from the test stand, SSC workers between 2 and 4 miles from the test stand would receive lower doses than the levels predicted at 0.6 mile.

Regulatory Guidelines and Standards. No federal ambient air quality standards exist for HCl. Therefore, the predicted air concentrations were compared with relevant occupational standards issued by the Occupational Safety and Health Administration (OSHA 1989), and with air quality guidelines recommended by the state of Mississippi and the National Research Council (NRC) Committee on Toxicology (NRC 1987) (see Table 5-1). A recommended air concentration (RAC) established by the EPA (55 FR 17862) for a 3-minute average HCl concentration from hazardous waste incinerator emissions was also considered for comparison; however, it was not deemed an appropriate comparison because

the 3-minute RAC was established for continuous 24-hour HCl emissions, while ASRM emissions exposure, even to persons directly downwind, will occur only for about ten minutes to two hours no more than 4 times per year with a few months between tests. A brief discussion comparing predicted HCl concentrations with appropriate existing regulatory standards or guidelines follows.

The maximum HCl concentration at 0.6 mile, the point of maximum instantaneous average air concentration, is 0.24 mg/m^3 , well below the OSHA promulgated maximum allowed occupational exposure level of 7.0 mg/m^3 (OSHA 1989). In addition, the state of Mississippi has derived a 24-hour average HCl air quality guideline for maximum HCl air concentration based on 1 percent of the American Conference for Governmental Industrial Hygienist (ACGIH) recommended occupational standard [threshold limit value (TLV)]. TLVs apply to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effects. As stated by ACGIH (1989), TLVs are based on the best available information from industrial experience, and from human and experimental studies. Although TLVs have received some criticism, they are routinely used by state and federal regulatory agencies to evaluate occupational exposures and are increasingly being used to develop ambient air quality standards (Calebrese and Kenyon 1989). Based on 1 percent of the ACGIH TLV of 7.5 mg/m^3 (ACGIH 1989), the Mississippi guideline permits a maximum 24-hour average HCl air concentration of 0.07 mg/m^3 (MBPC 1990). This 24-hour average HCl concentration guideline is approximately 9 times higher than the expected concentration at 4.2 miles (0.0088 mg/m^3), the point of maximum 24-hour average HCl concentration indicating that no adverse health effects from HCl emissions to workers or the general population are projected. As indicated in Table 5-1, the 24-hour average concentration of HCl is lower between 2 and 4 miles from the test stand than at 4.2 miles. Therefore, no SSC workers would experience adverse health effects from HCl emissions.

A more appropriate guideline to compare with ASRM HCl emissions is the short-term public emergency guidance levels (SPEGLs) developed by the National Research Council Committee on Toxicology specifically for short-term, intermittent community exposures occurring during Space Shuttle launches. To conservatively protect sensitive populations such as infants, children, the elderly, and people with respiratory diseases from the large quantities of HCl emitted during Space Shuttle launches, the Committee on Toxicology recommended a 1-hour SPEGL of 1.5 mg/m^3 (NRC 1987). The Mississippi Bureau of Pollution Control further limits HCl daily exposure to a 24-hour average of 0.007 mg/m^3 to protect the public. In other words, HCl concentrations averaged over a 1-hour and 24-hour time period should not exceed 1.5 mg/m^3 and 0.07 mg/m^3 , respectively. As shown in Table 5-1, the maximum predicted 1-hour and 24-hour HCl air concentrations at 4.2 miles from the test stand are approximately 10 times lower than either of these guidelines and therefore are considered protective of the health and safety of workers as well as off-site populations. Again, average concentrations at locations closer than 4.2 miles will be lower than the maximum at 4.2 miles.

LONG-TERM HEALTH EFFECTS

ASRM tests will be conducted infrequently (4 times per year) and are of short duration (2 minutes), resulting in predicted HCl concentrations that are well below guidelines for maximum 1-hour and 24-hour exposures established by the National Research Council, the state of Mississippi, and OSHA. Therefore, no long-term health effects from HCl emissions are anticipated. While evidence that cumulative health effects may occur from acute, intermittent exposures to certain toxic organic compounds such as PCBs or dioxins, these compounds are entirely different from ASRM type emissions. While hydrophobic compounds (i.e., compounds not soluble in water but which may be soluble in fats such as PCBs and dioxins) persist within the body fats for long periods of time, hydrophilic compounds (i.e., compounds soluble in water) such as HCl do not accumulate, are metabolically controlled, and are readily eliminated from the body. No evidence of cumulative health effects from intermittent exposures to low-levels of HCl was found. Since occasional exposures to levels of HCl from ASRM testing are sufficiently low to prevent adverse acute effects, no adverse chronic effects are expected.

5.3.2 Potential Health Effects of Acid Aerosols

Acid aerosols are suspended solid or liquid particles with a pH less than 7, resulting from the movement of acids from the gaseous phase into liquid aerosols. The available information on concentration patterns and human exposures to atmospheric aerosols is sparse (EPA 1988b). Available data indicate that the atmospheric concentrations of acid aerosols depend upon variable conditions such as relative humidity, temperature, and the background composition of other pollutants. Insufficient data exist to quantify the extent of conversion of gaseous HCl to aqueous aerosols in the atmosphere. However, hydrogen chloride readily associates with water such that atmospheric HCl is likely to exist to some degree in the aerosol form (see Section 4.2.2).

SHORT-TERM HEALTH EFFECTS

Toxicological Considerations. No studies were found regarding potential health effects associated with exposure to HCl-formed acid aerosols. Most of the research conducted in this area has focused on strong acid sulfates such as sulfuric acid and ammonium bisulfate. However, since anhydrous HCl gas is highly reactive with water and exerts its irritant effect by desiccation (dehydration) and corrosion, exposures to HCl gas are potentially more dangerous than exposures to HCl aerosols (NRC 1987; EPA 1969). It is also possible that aerosols are more efficiently deposited than are gases.

Two important chemical defenses against inhaled acids include airway surface liquid buffers (mucous) and endogenous ammonia (EPA 1988b). Endogenous ammonia and the buffering capacity of mucous material in the respiratory tract are capable of neutralizing low concentrations of acid aerosols and, hence, play an important role in determining the airway toxicity of acid aerosols (EPA 1988b). Respirable acid particles (i.e., smaller than 10 microns) are rapidly neutralized by resident ammonia and airway mucous in the body.

The total capacity of the mouth and respiratory tract to neutralize inhaled acids is substantial and variable depending on particle size, concentration of ammonia in the airways, concentration of acid in the aerosol, and residence time of aerosol in the airways (EPA 1988b).

Little information is available to precisely quantify the extent of HCl aerosol formation from ASRM testing. Assuming that all of the HCl gas resulting from ASRM testing forms acid aerosols, which is not expected, the maximum instantaneous HCl concentration resulting from ASRM testing (0.24 mg/m^3) may be compared, as a surrogate, to concentrations of sulfuric acid aerosol which have been reported to cause no adverse health effects in studies with human volunteers. For example, no adverse effects on pulmonary function (as measured by expiratory volume) have been reported in normal subjects exposed to sulfuric acid aerosols below 0.5 mg/m^3 (EPA 1988b).

Small changes in spirometry (measurement of breathing capacity) have been observed in normal subjects after laboratory exposure to 1.0 mg/m^3 sulfuric acid aerosols, although these changes have not been consistently observed. There is, however, one report of a small reduction in pulmonary function (i.e., forced expiratory volume in one second; FEV_1) in nine adolescent asthmatics exposed in the laboratory while exercising in an environment with concentrations of sulfuric acid aerosols as low as 0.068 mg/m^3 (Koenig et al. 1989). The reported reduction in FEV_1 in those subjects was 6 percent. A reduction in FEV_1 of 5 percent is considered significant for some asthmatics. The reported reduction in FEV_1 is, in all probability, rapidly reversible after exposure ceases. At the concentration studied, no effects were observed in adult asthmatics. It is not absolutely clear that it is appropriate to compare HCl aerosols to sulfuric acid aerosols since sulfuric acid has over twice the effective acidity as HCl. Also, the small reduction in respiratory volumes was observed in a small group (sample size of 9) of sensitive individuals. The results of the Koenig et al. study (1989) must be considered preliminary and should not be extrapolated to the general population surrounding SSC.

Assuming a worst case where HCl and sulfuric acid are equally effective at producing respiratory effects (although it is believed that sulfuric acid is more toxic), the maximum possible concentration of HCl aerosol (0.24 mg/m^3) is below the no-effect level for sulfuric acid (0.5 mg/m^3). On the basis of this information, adverse health effects in normal subjects from HCl emissions is not projected. Only one study using 9 subjects showed any effects at levels below the predicted maximum of 0.24 mg/m^3 . Therefore, it is projected that ASRM testing will not result in significant or prolonged health impacts even to exercising adolescent asthmatics since HCl concentrations from ASRM testing are short lived. The maximum one-hour average concentrations are more applicable to exercising asthmatics and are 1.6 times lower than the maximum values at 0.6 mile from the test stand (Table 5-1).

Regulatory Guidelines and Standards. Currently, there are no federal ambient air quality standards or guidelines, nor any occupational standards, specifically for acid aerosols. However, EPA is considering listing acid aerosols as a separate criteria pollutant

(EPA 1988b). Because of the absence of any guidance, exposure to HCl aerosols was evaluated in this assessment based solely on the sulfuric acid data.

LONG-TERM HEALTH EFFECTS

As stated above, it is not expected that any short-term health effects will occur since ASRM testing is conducted infrequently, and for short durations. Furthermore, no long-term health effects are expected from potential acid aerosol formation. This conclusion is justified based on the analyses described in Section 4.2.2, which show that formation of HCl aerosols is limited in atmospheric conditions with a relative humidity less than 100 percent. Even assuming that all of the HCl dissolves in aqueous aerosols, the ambient HCl concentration would be so low (Table 5-1) that no long-term health effects are anticipated.

5.3.3 Potential Health Effects of Acid-Coated Particles

NASA investigations of ground-level aluminum oxide particulates from Space Shuttle emissions indicate that some aluminum oxide particles that collected on the ground had a slight acidic coating, and some chlorides were also found (NASA 1983). Upper-level airborne samples of aluminum oxide in the Shuttle plume indicate that some chlorides formed on the particles (Cofer et al. 1987). As explained in Section 4.2.2, the conversion of aluminum oxide to aluminum chloride does not appear to be thermodynamically favored at ambient temperatures. At the temperatures and the water content expected to be found in the atmosphere, it is more favorable for the chloride to be converted to the oxide (the nontoxic, stable form) rather than the oxide to the chloride. To address the specific concern that acid-coated particles may have an enhanced effect on respiratory function (i.e., greater combined effect than either acid aerosols or particulates alone), the following section briefly discusses the toxicology of acid-coated particles as they apply to ASRM testing.

A review of the scientific literature demonstrated that information on the toxicological effects of HCl acid-coated aluminum oxide particles was sparse. Wohlschlager et al. (1975) conducted experiments with HCl, hydrogen fluoride, and aluminum oxide to examine the potential synergistic, additive, or antagonistic effects due to simultaneous exposures. They found no synergistic or additive effect on lethality due to simultaneous, 60-minute exposure to HCl and aluminum oxide. In recent studies, Amdur and Chen (1989) reported an enhanced effect (i.e., a cumulative effect greater than the sum of the effect of each individual pollutant) on bronchial reactivity in guinea pigs exposed to zinc oxide particles that were coated with sulfuric acid aerosols. These findings appear to suggest that sulfuric acid-coated particulates enhance the pulmonary effects of acid aerosols; however, these results are not directly applicable to aluminum oxide and HCl emissions at SSC for the following reasons:

- Zinc oxide alone affects pulmonary function at concentrations around 5 mg/m³ (EPA 1987b), while aluminum oxide produces no observable effect on lung function even at high concentrations (EPA 1990). Furthermore, the size range of particles used in this study (median less than 0.05 mg) is much smaller than those emitted from ASRM testing.

- The repeated exposures in the Amdur and Chen study were more intense and of longer duration (3 hours per day for 5 consecutive days) than those planned for ASRM testing (less than 2 hours per day, 4 days per year), although cumulative effects were observed at sulfuric acid concentrations as low as 20 mg/m³.
- The results of the Amdur and Chen study have not been substantiated with other compounds (e.g., HCl). Interestingly, animals exposed 3 hours each day Monday through Friday and then rested on Saturday and Sunday, displayed normal pulmonary functions when tested on Monday (Amdur and Chen 1989). This suggests that some mechanism of repair occurs following the initial adverse effect. Further, the post-exposure lung function tests on Monday were also normal. It would therefore appear that despite evidence that sulfuric acid-coated zinc oxide particles produce an enhanced effect on pulmonary function, a brief period of nonexposure enabled full recovery.

In summary, given the low emission concentrations associated with ASRM testing, the benign nature of aluminum oxide (see Section 5.3.4), and the quick recovery time of animals exposed to sulfuric acid-coated zinc oxide, no enhanced acute or chronic adverse pulmonary effects from acid-coated aluminum oxide particles are expected.

5.3.4 Potential Health Effects of Aluminum Oxide Exposures

SHORT-TERM HEALTH EFFECTS

Toxicological Considerations. Aluminum oxide is the primary product of aluminum combustion. It is a relatively stable compound which is insoluble in water, dilute acids, and basic solutions. Aluminum compounds are normal components of the human diet, and people ingest aluminum in both food and water. The normal intake is between 10 to 100 mg/day. Most soft tissues in the body contain between 0.2 to 0.6 mg of aluminum per gram of tissue (Goyer 1986). Aluminum oxide is poorly absorbed from the intestines and lungs.

Aluminum oxide is considered an inert compound. After an exhaustive review of the toxicological literature, the EPA concluded that no evidence of acute (short-term) toxicity, reproductive effects or mutagenic effects of aluminum oxide have been reported in exposed workers or laboratory animals (EPA 1990; ACGIH 1989). The benign nature of aluminum oxide is illustrated by one study of the respiratory effects of fiber-epoxy dusts on rats (Lucht et al. 1989) which used aluminum oxide as an inert control dust. Control rats exposed to aluminum oxide in this study did not develop fibrotic lesions. In addition, Wohlschlager et al. (1975) exposed rats to up to 478 mg/m³ of aluminum dust for 60 minutes with no immediate post-exposure toxic effects and no observed toxic effects at the 14-day sacrifice.

Regulatory Guidance and Standards. Aluminum oxide is considered an inert, or unreactive, "nuisance" particulate with no significant toxic effects to lungs or other body organs (ACGIH 1989; EPA 1990). Since federal ambient air quality standards do not exist for aluminum oxide and it is considered as particulate matter, the projected air concentrations associated with ASRM testing were compared with the average 24-hour national ambient air quality standard for nonspecific particulate matter (e.g., dust, smoke, etc.) of 0.15 mg/m^3 (EPA 1989b). The expected 24-hour average ground-level (i.e., breathing zone) air concentration of aluminum oxide at 4.2 miles from the ASRM test stand (the point of maximum 24-hour average concentrations) is 0.015 mg/m^3 , which is 10 times lower than the national ambient air standard for particulate matter. The maximum background ambient 24-hour concentration of particulate matter in air at SSC is 0.046 mg/m^3 . The combined concentration of ambient particulate matter and the maximum 24-hour average aluminum oxide is 0.061 mg/m^3 ($0.046 + 0.015 \text{ mg/m}^3$), still well below the national air quality standard. Therefore, ASRM emissions will not increase the ambient concentration of particulate matter above the national ambient air quality standard to a level considered unhealthy. Furthermore, the occupational limit for an 8-hour exposure to aluminum oxide is 10 mg/m^3 (OSHA 1989). This occupational limit is 25 times higher than the predicted maximum instantaneous aluminum oxide concentration at 0.6 mile. Given the relatively inert properties of aluminum oxide and the low predicted maximum air concentration associated with ASRM testing, no short-term human health effects are projected for SSC workers or residents in off-site communities.

LONG-TERM HEALTH EFFECTS

There is no evidence of chronic (long-term) toxicity, carcinogenicity, reproductive effects, or mutagenic effects of aluminum oxide reported in workers or laboratory animals (EPA 1990; ACGIH 1989). Some studies have indicated minimal fibrogenic growth (development of fibers) in the lungs of long-term workers exposed to high concentrations of complex mixtures of aluminum dust, aluminum oxide and silica (Dinman 1988).

Reports of health effects due to heavy and prolonged (life-time) aluminum oxide dust exposure to industrial workers such as aluminum smelter workers (Gilks and Churg 1987) cannot be compared to the ASRM testing because the exposure duration and concentrations from ASRM testing are dramatically lower. In an animal inhalation study, aluminum oxide was efficiently cleared from the lung and demonstrated little or no fibrogenic potential (Sjogren et al. 1985).

Recognizing the toxicologically inert properties of aluminum oxide, EPA recently deleted nonfibrous aluminum oxide from its list of toxic chemicals (EPA 1990). EPA also determined that nonfibrous aluminum oxide did not meet the criteria for causing acute and chronic human health effects, carcinogenicity, or environmental toxicity (EPA 1990). EPA concluded that there was no evidence that nonfibrous aluminum oxide causes or "can be reasonably expected to cause" adverse health and/or environmental effects (EPA 1990).

Given the low aluminum oxide concentrations projected from ASRM emissions and the generally inert toxic properties of aluminum oxide, exposure from ASRM testing will not result in adverse long-term health effects.

Human health concerns have been raised about the possible connection between aluminum and neurological disorders such as Alzheimer's disease. It should be emphasized that ASRM emissions are comprised almost exclusively of chemically stable (i.e., not bioavailable) aluminum oxide with trace amounts of aluminum chloride. There has not been any link between aluminum oxide and Alzheimer's disease. However, because of the public's concern, a further comprehensive literature review was conducted on aluminum and Alzheimer's disease. This literature review is summarized below and presented in detail in Appendix F.

Although aluminum compounds are known to induce certain neurological effects in laboratory animals and is present in high concentrations in damaged neurons of Alzheimer's patients and persons with other neurological disorders, its link as a cause of Alzheimer's disease or even its role in the progress of the disease has not been scientifically established. EPA, in a recent review of aluminum toxicity, had found no evidence that supports the theories that aluminum plays a pathological role (i.e., causes disease) in Alzheimer's disease, amyotrophic lateral sclerosis and Parkinson-dementia (EPA 1990). While there have been many popular articles written on the subject and many theories have been advanced, there is a lack of compelling or sufficient evidence which supports the hypothesis of any direct causal role of aluminum in Alzheimer's disease development. Several research groups currently continue to investigate the role of aluminum in Alzheimer's disease.

It is not clear whether the high levels of aluminum that are present in the neurofibrillary tangles (twisted helical neurons in the brain) of Alzheimer's patients is a cause or a secondary effect as a result of the disease (Crapper McLachlan 1985). As presented in Appendix F, there are certain observations that indicate some role of aluminum in Alzheimer's disease as well as observations that seem to refute an etiological (causative) role. For example, in Guam Parkinson-dementia subjects, the neurofibrillary tangles in the brains of persons with the disease can contain up to 300 times the aluminum concentration compared to the adjacent nontangled neurons of those of normal subjects (Perl et al. 1982; Perl et al. 1986). Whatever combination(s) of genetic and environmental factors that may be responsible for neurological disorders on Guam, it requires a long time (around 20 years) for immigrants to develop such disorders. Similarly, patients with Alzheimer's disease also have elevated aluminum levels in tangle-bearing neurons. Injection of aluminum compounds into the brain of laboratory animals produces neurofibrillary tangles, although structurally different from those seen in Alzheimer's disease. Furthermore, an epidemiological study reported a slight increased risk of Alzheimer's disease in regions with elevated aluminum levels in drinking water relative to areas with lower aluminum levels (Martyn et al. 1989). However, the results of this study are extremely controversial due to poor estimation of exposures, study design, and other factors.

Central to the question of the role of aluminum in neurological disorders is "How does the aluminum pass through the blood-brain barrier (a fatty layer surrounding the brain and central nervous system which prevents many chemicals from entering the brain), since it is not normally transported?" This implies a breakdown of the barrier to allow the aluminum to migrate to the neurons and then associate with the neurofibrills.

Most of these studies have produced rather interesting results but have not directly associated aluminum exposure as a cause of Alzheimer's disease. Therefore, at this time, a conclusive determination of whether aluminum plays a significant role in the development of neurological disorders is not possible. However, in trying to assess whether ASRM testing would have any adverse effects, it is important to recognize that the concern and controversy about Alzheimer's disease pertains to exposure to unknown species of aluminum. Samples taken from actual Space Shuttle emissions (NASA 1989a), and from ASRM dispersion modeling, indicate that emissions are comprised almost exclusively of nonfibrous aluminum oxide that are relatively environmentally immobile and inert. In addition, since the predicted concentrations of aluminum oxide are quite low at 4.2 miles from the test stand (0.015 mg/m³, maximum 24-hour avg.) and aluminum oxide is not readily absorbed into the body, the contribution of ASRM emissions to any overall aluminum intake appears to be exceedingly small. Average daily intake in food and water by persons not exposed to ASRM testing varies between 5 and 50 mg. Therefore, given the information available in the literature and given the exposure conditions at points of maximum air concentration, there does not appear to be any enhanced risk of neurological disorders, including Alzheimer's disease, associated with ASRM testing.

5.4 SUMMARY AND CONCLUSIONS

As noted in the FEIS, and as further documented in these supplemental evaluations, potential exposures to HCl and aluminum oxide in ASRM emissions are not anticipated to result in adverse human health impacts. This conclusion is based on several key factors: 1) predicted HCl concentrations are below ambient air quality criteria; 2) no significant health impacts from acid aerosols are expected based on comparison with sulfuric acid aerosol toxicity; and 3) the predicted concentrations of aluminum oxide do not exceed the criteria for particulate matter.

Although aluminum may induce certain neurotoxic effects and is present in the neurofibrillary tangles of patients with Alzheimer's disease and Parkinson-dementia, a causal relationship between environmental exposures to aluminum and Alzheimer's disease has not been established. While aluminum oxide will be a component of ASRM exhaust, it will not exist in a bioavailable form and is not easily absorbed into the body. There has not been any link between aluminum oxide and Alzheimer's disease. Air dispersion modeling indicates aluminum oxide will be present only briefly and at low concentrations as a result of ASRM testing. Therefore, it is highly unlikely that ASRM emissions would significantly contribute to overall normal aluminum intake such that it could induce neurological disorders such as Alzheimer's disease. Nevertheless, to minimize public exposure, ASRM tests will be conducted only in meteorological conditions favorable

5.5 CONSULTANT REVIEW

A consultant panel of recognized medical researchers was assembled to review and critique the potential for human health effects resulting from static testing of the ASRM at SSC. The panel included the following three medical researchers:

Daniel Perl, M.D., is a professor of Pathology and Psychiatry and is the Director of the Neuropathology Division at the Mount Sinai Medical Center in New York City. Dr. Perl is an M.D. with over 20 years of experience in neuropathology. Dr. Perl was featured in a December 18, 1989 Newsweek article on Alzheimer's disease and its possible connection with aluminum. Dr. Perl has been conducting research on the link between Alzheimer's disease and aluminum for over ten years and is widely recognized as one of the leaders in his field.

Leonard Kurland, M.D., Dr.P.H (Public Health) is a Senior Consultant and Professor of Epidemiology at the Mayo Clinic in Rochester, Minnesota. Dr. Kurland has over 45 years of experience as a human health researcher and was involved in some of the earliest studies of Alzheimer's disease and Parkinson-dementia on the island of Guam.

Lucio Costa, Ph.D. is a Research Associate Professor in the Department of Environmental Health at the University of Washington in Seattle, Washington. Dr. Costa has over 13 years of experience conducting research in neurotoxicology. Dr. Costa is internationally recognized as an expert on the neurotoxic effects of pesticides, metals and environmental chemicals.

Remarks from these three experts are presented in Appendix G. Their remarks have also been incorporated into this document and in the more detailed discussion (Appendix F) of the potential role of aluminum in the development of Alzheimer's disease.

5.6 PUBLIC AND EMPLOYEE HEALTH AND SAFETY FOR CASE-RUPTURE AIR EMISSIONS

5.6.1 INTRODUCTION

Accidental exposures of SSC workers and the public to air emissions resulting from unexpected combustion of ASRM solid fuel were examined in the FEIS. As discussed in the FEIS, the presence of voids in the cured rocket motor propellant could lead to case rupture during static testing. Case rupture may also occur as the result of structural flaws in the case, including the insulation, seals, adhesives, or other case materials. In addition to the health and safety impacts due to an explosive case rupture, the FEIS addressed the air impacts resulting from uncontrolled burning of propellant that may be thrown onto the ground. In order to address concerns regarding the exhaust plume behavior and air

concentrations specific to a case-rupture accident, the emissions and dispersion were modeled according to the methodology described in Section 4.2.1. This section summarizes the human health effects of case-rupture emissions.

5.6.2 MODELING

The exhaust emissions and plume behavior during a case-rupture accident were modeled according to the protocol developed in Section 4.2. A case rupture of a 1.206-million-pound fuel segment was presumed to occur during static testing and to last for 300 seconds. This time duration was obtained from data provided in the Final Environmental Impact Statement for the Space Shuttle Solid Rocket Motor Program at Thiokol-Promontory, Utah (NASA 1977). Under the case-rupture scenario, the solid fuel would continue to burn until all the fuel was consumed. The temperature of the exhaust emissions would be the same as under normal testing conditions (6,000°F); however, the exhaust would not be thrust out the nozzle at high velocities. Much of the exhaust would be emitted from the point of rupture and from any fuel spilled onto the ground.

The results of the PCAD modeling indicate that the extremely hot exhaust plume will buoyantly rise to a final centerline elevation of 10,000 feet. This is approximately 3,000 feet lower than the final elevation of the exhaust plume from normal static testing (Section 4.2.2). PCAD also predicted that the radius of the plume would be about 8,000 feet. The composition of the exhaust would be the same as during normal static testing.

The PCAD results were used as inputs to the INPUFF 2.3 dispersion model to calculate the ground-level concentrations. The modeling results predicted a maximum 24-hour HCl concentration of 0.013 mg/m³ at a distance of 2.5 miles from the test stand. This is approximately 5 times less than the 24-hour HCl standard. The concentrations of aluminum oxide and aluminum chlorides following case rupture would also be below routine regulatory guidelines.

5.6.3 HUMAN HEALTH EFFECTS

The human health effects to SSC workers within a 2.5-mile radius of the case-rupture accident would be similar to those discussed in the previous sections. The ground-level concentrations would increase slightly but would still be far below all regulatory levels and, therefore, no adverse effects would be anticipated.

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7.0 CONTRIBUTORS TO THE SFEIS

This SFEIS for the ASRM Program was prepared for the National Aeronautics and Space Administration by Ebasco Services Incorporated. An external panel of reviewers contributed comments reflected in the discussion of human health effects. Preparers of each SFEIS section are noted in Table 7-1. Ebasco had responsibility for completion of the SFEIS under the direction of NASA. NASA is responsible for coordination, management, review, and acceptance of the SFEIS.

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Table 7-1. Contributors to the SFEIS.

Responsible Person	Executive Summary	Chapter								Appendix						
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Table 7-1. Contributors to the SFEIS (continued).

Responsible Person	Executive Summary	Chapter								Appendix					
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8.0 AGENCY CONSULTATION

Table 8-1 summarizes government agencies that were consulted in the preparation of the SFEIS.

Telephone conversations or visits with some of the individuals listed in Table 8-1 may also be cited in the main body of the text. References for those citations are provided in Section 6.0.

Table 8-1. Agency Consultation (continued).

Name	Agency	Location	Subject of Consultation
Bob Israel	Environmental Protection Agency	Washington, DC	EPA delisting of aluminum oxide (4/11/90)
Edward McGregor	U.S. Army Corps of Engineers	Vicksburg, MS	Wetland Evaluation Technique II (4/13/90)
Larry Marcy	U.S. Army Corps of Engineers	Vicksburg, MS	Arrangements for site visit; spoil status of existing deposit areas (4/6/90); Site visit (4/12/90)
Steve Miranda	Mississippi Cooperative	Mississippi State, MS	Life history of southern Mississippi native fish (6/22/90)
Jim Morris	Mississippi Bureau of Pollution Control	Jackson, MS	Mississippi state water quality criteria (5/9/90)
Kent Schreiber	U.S. Fish and Wildlife Service	Kearneysville, WV	Acid rain effects on wildlife (5/3/90)
Tommy Thornhill	U.S. Fish and Wildlife Service	Daphne, AL	Sensitive areas for fish (3/29/90); need for fall/late summer plant & animal surveys (4/25/90)
Dwight Wylie	Mississippi Bureau of Pollution Control	Jackson, MS	Origin and application of 3-minute HCl Recommended Air Concentration (RAC) to the NASA ASRM project (5/21/90)
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APPENDIX A
Wetland Mitigation Report

WETLAND MITIGATION PLAN
FOR
NASA ASRM STATIC TEST FACILITY
STENNIS SPACE CENTER
MISSISSIPPI

Excerpts from 404 Permit Application submitted to the
Vicksburg District, U.S. Army Corps of Engineers,
May 9, 1990

EXECUTIVE SUMMARY

This mitigation plan addresses the wetland impacts of the proposed Advanced Solid Rocket Motor (ASRM) Static Test Facility at Stennis Space Center (SSC) in Hancock County, Mississippi. The objective of the mitigation plan is to reduce impacts by 1) avoiding wetlands through an alternatives analysis for site selection, 2) minimizing impacts by redesign of project facilities and implementation of appropriate construction techniques, 3) reducing impacts during the life of the project through maintenance operations, and 4) compensating for unavoidable impacts by replacing or providing substitute wetland resources. The approach taken in developing this plan was: inspect sites to be impacted by ASRM facilities proposed, assess functional values of wetlands to be filled (primary impact), and outline mitigation measures to meet the expected loss of wetland functions.

Pine and bottomland hardwoods are the two principal forest cover types in the proposed ASRM site. Pine plantation forestry is the present land use of the vegetated portions of the proposed ASRM site; consequently, silvicultural practices have had a significant influence on species composition and surface drainage. Extensive ditches remove surface water rapidly and drain the land for improved pine growth. Pine is additionally favored by planting. Also, the bottomland hardwood drainage swales are much narrower and reduced in size from natural conditions because of pine planting.

The principal values of the wetlands impacted (filled) by the ASRM infrastructure are biotic and hydrologic in character. The primary biological function of the pine flatwood is a wildlife habitat. However, forest management has converted what appears to have been a hardwood or hardwood-pine habitat into monotypic pine. An additional habitat function found in the pine flatwood forest is the support of pitcher plant bogs. These bogs are unique habitats that have also been adversely impacted by forest management (ditching and overplanting of pine). Similarly, the planting of pine in swales has degraded the bottomland hardwood habitat. The result of pine plantation management has been to impair the wildlife function by reducing hardwood (or mixed hardwood-pine) forests.

The principal hydrologic functions of the impacted areas are flood storage and desynchronization of storm flow. The ASRM Static Test Facility is to be located in the headwaters of the Jourdan River and Pearl River watersheds. The microtopography results in many storage depressions. Detained runoff provides desynchronous stormflow, as well as subsequent infiltration and subsurface flow to augment stream baseflows. At present, the ubiquitous drainage ditches in the proposed ASRM site reduce both storage and flow desynchronization.

Once the SSC was selected as the site for static test firing of the motor, various sites within the SSC Fee Area were evaluated. In NASA's evaluation of the proposed site, three criteria required the site to be relocated: the unnecessary impact on the bottomland hardwood wetlands of Lion Branch, the inefficient use of the Fee Area property, and the excessive length of the transport road. Quantity/distance requirements were also determined for ASRM facilities. Overall, SSC Facility Master Plan guidelines established specific site zones for hazard testing in order to provide worker safety. These constraints limited the location of the ASRM Static Test Facility to the eastern portion of the Fee Area.

The parking lots at the individual ASRM facilities have been redesigned from the original size to provide only the minimum number of spaces required during normal operations. Finish grade elevations on roadways have been set as low as practicable to insure the minimum impact on wetland areas, while maintaining adequate safety and drainage design requirements. Although the Test Stand location is set due to safety and SSC Facility Master Plan guidelines, other facilities such as the Test Control Center, Engineering Operations Building and the Equipment Building have been located to minimize wetland disturbances.

Compensation for the 68.4 acres of fill will take three forms: 1) restoration of the hydrologic functions by filling ditches in the flatwoods and building low berms across selected drainage swales; 2) augmentation of bottomland hardwood forest cover for wildlife habitat in the flatwoods by discontinuing pine plantation management; and 3) enhancement of the unique pitcher plant bog habitat by controlled burning in selected areas. Each of these items can be accomplished in the vicinity of the ASRM Static Test Facility.

I. WETLAND FUNCTIONS AND MITIGATION GUIDELINES

Forested wetlands of the southeast provide important functions that include:

- o Biotic values, such as biological diversity and uniqueness, food chain support, and wildlife habitat;
- o Hydrologic values, such as flood abatement and control (by storage and desynchronization of flow), groundwater recharge, improved water quality, and contribution to base flow;
- o Economic values, such as timber and crawfish production; and
- o Socio-cultural values, such as aesthetics, education, and recreation.

These functions are of public value and necessitate: 1) avoiding wetlands through an alternatives analysis for site selection, 2) minimizing impacts by redesign of project facilities and implementation of appropriate construction techniques, 3) reducing impacts during the life of the project through maintenance operations, and 4) compensating for unavoidable impacts by replacing or providing substitute wetland resources.

As a practical matter, opportunities for replacement of wetland functions are unique to each project. Successful wetland compensation requires a plan that recognizes the ecology and land use of the project area. Compensation for the loss of wetland functions, in the case of this project area, is to be accomplished by restoration of degraded natural wetland and enhancement of the wetland functions of existing natural wetland. Creation of wetland from upland, a third possible form of compensation, is considered the least desirable option due to the large amount of jurisdictional wetland in the project vicinity. Thus uplands, rather than wetlands, are the locally scarce wildlife habitat. Two guidelines for wetland compensation were followed:

- o adjacency - the remedial activity should take place close to the impact, ideally in the same wetland or at least in the same drainage basin; and
- o replacement in kind - the wetland functions replaced should be similar to those lost.

Physiography

The majority of the proposed ASRM Static Test Facility (See Figure 1) lies along the western edge of the Jourdan River watershed. Total wetlands impact from the ASRM infrastructure is summarized in Table 1. Standby Road follows an east-west drainage divide that separates intermittent streams that flow southeast to Devil's Swamp, from those streams (Lion Branch, Double Bay, Wolf Branch) that flow east to Catahoula Creek. Intermittent drainages and ditches south of Standby Road and west of Ruffin Road are part of the Pearl River drainage system. The topography is nearly level to gently sloping, and the landscape consists of broad, wet flats and drainageways, with low upland ridges. Typically, soils are poorly or somewhat poorly drained (Smith et al. 1981).

Flora Description

Pine and bottomland hardwoods are the two principal forest cover types in the ASRM site (Esher and Bradshaw 1988). The pine forest occurs on the broad wet flats, and is referred to as pine flatwood. Slash pine (*Pinus elliottii*) dominates the community, with hardwood species such as pond cypress (*Taxodium ascendens*), tupelo (*Nyssa sylvatica sylvatica*), sweet bay (*Magnolia virginiana*), red maple (*Acer rubrum*), red bay (*Persea borbonia*), and oak (*Quercus* spp.) occurring as individuals or small isolated stands. The bottomland hardwood forest occurs along intermittent drainages. Its dominant tree species are mostly the same as those listed above, but in different and varying proportions.

Presently, pine plantation forestry is the land use of the proposed ASRM Static Test Facility site and the surrounding 200-square-mile Buffer Zone. Except for the bottomland forest along Lion and Wolf branches and south near the barge canal, commercial silvicultural practices have had a significant influence on species composition and surface drainage in the proposed ASRM site. Extensive ditches remove surface water rapidly and drain the land for improved pine growth. Pine reproduction is favored by planting, and hardwoods are eliminated by control burning and mechanical site preparation. Most of the flatwoods are in monotypic pine plantations; the bottomland hardwood drainage swales are much narrower and reduced in size from natural conditions because of pine planting.

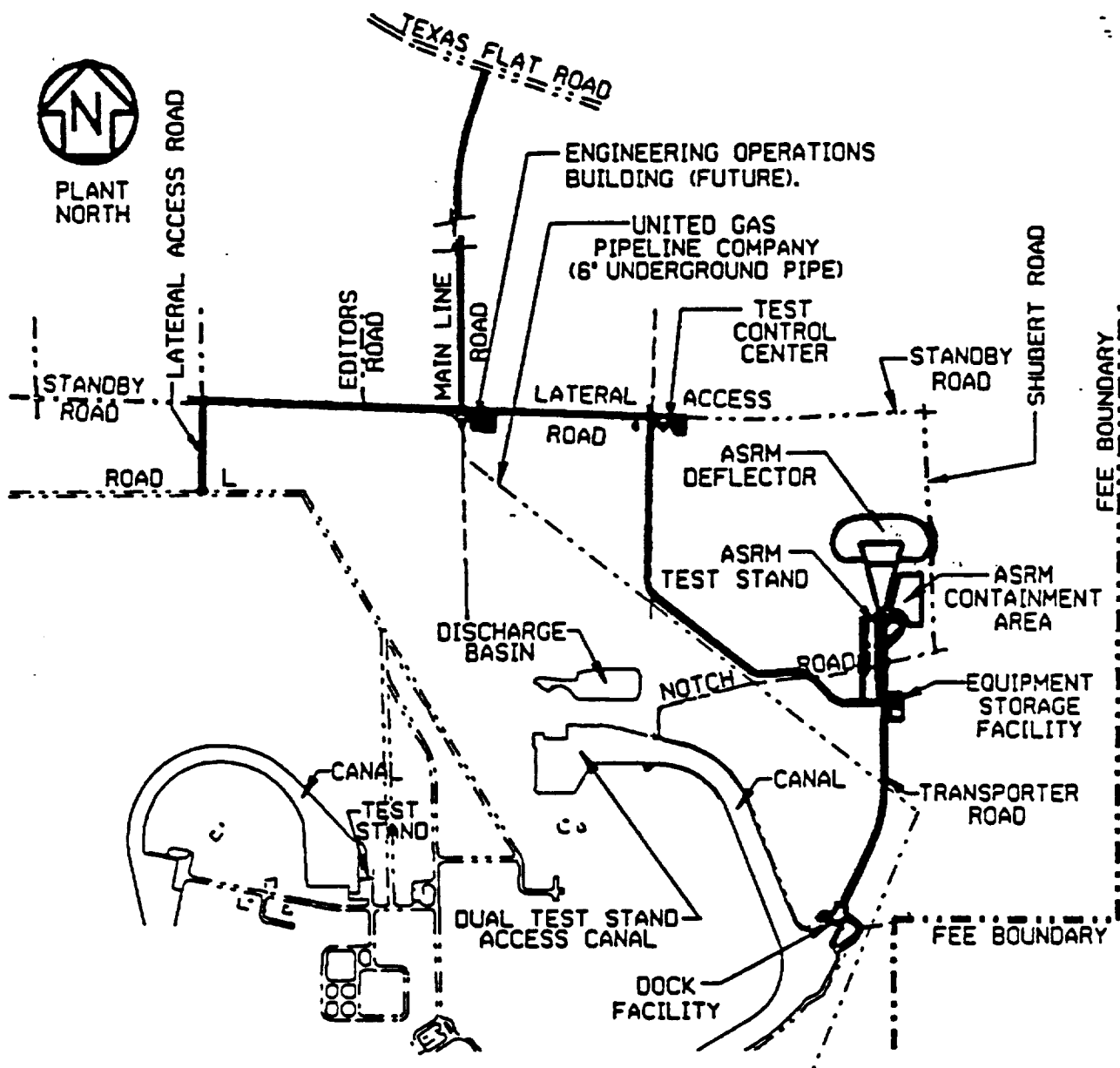
A unique pitcher plant (*Sarracenia*) bog vegetation community is disappearing regionally from the flatwoods largely as a result of commercial plantation forestry. Several species of insectivorous plants are found in these open, nutrient-poor, wet sites in the flatwood forest. Maintaining these openings depends on frequent fires hot enough to kill competing shrubs and pine, but not so hot as to injure roots (Folkert 1982). Because of

their relatively small size and scattered occurrence in the flatwoods, the bogs are often planted in pine and become part of the plantation. The construction of ditches to improve pine growth also adversely alters the soil moisture regime required by the bog flora. (See Attachment A-I., Floristic Analyses.)

Fauna Description

Terrestrial fauna primarily dependent on bottomland hardwoods include wild turkey (*Meleagris gallopavo*), gray and fox squirrels (*Sciurus* spp.), gray fox (*Urocyon cinereoargenteus*), and raccoon (*Procyon lotor*). These and many other species need mast for subsistence at least seasonally, or the cavities of old trees in which to shelter and nest. Associated with them are others, like the striped skunk (*Mephitis mephitis*), with a small home range and a daily dependence on surface water. In most of the area's hardwood habitat, however, there is insufficient surface water to attract or support wood duck (*Aix sponsa*), beaver (*Castor canadensis*), or muskrat (*Ondatra zibethicus*). Fish occur only in the permanent water of the biggest streams and ditches. From these, crawfish extend their foraging some distance up into the pine flatwoods.

Management of the pine flatwoods partly imitates the natural processes (wind, fire) that periodically are used to set back the natural forest succession. Openings are created now in a more orderly fashion by roads, thinnings, and small clear-cuts, but the effect is much the same. Among the better-known game species in need of low food and cover are rabbits (*Sylvilagus* spp.), bobwhite quail (*Colinus virginianus*), and white-tailed deer (*Odocoileus virginianus*). However, because the pine forest is kept at a relatively early stage of ecological succession, the diversity associated with natural clearings in a mixed pine-hardwoods community of old-growth trees is never attained. (See Attachment A-II., Wildlife Habitat Evaluation.)



TEST LOCATION AREA MAP
N.T.S.

NASA

JOHN C. STENNIS SPACE CENTER
STENNIS SPACE CENTER, MS 39529

FIGURE 1
APRIL 27, 1990

TEST LOCATION
AREA MAP

TABLE 1. WETLAND IMPACTS OF THE ASRM INFRASTRUCTURE.

FACILITY	ACREAGE OF CLEARING & GRUBBING	ACREAGE OF FILL	ACREAGE OF IMPERVIOUS SURFACE	ACREAGE OTHER IMPACTS (cut)	FILL QUANTITIES (yds ³)
Engineering Operations Building	4.6	2.1	1.4	--	15,700
Test Control Center	3.6	2.0	1.3	--	15,600
Equipment Storage Building and Test Stand Area	24.9	12.8	5.4	--	86,818
Deflection Ramp	37.9	23.6	5.5	5.0	1,060,800
Test Range	145	--	--	--	--
Dock Area	6.1	3.5	1.4	--	30,650
Roadways Total					
Main Line	35.2	8.4	9.3	7.1	20,925
Lateral Access	34.4	9.7	7.6	0.5	17,204
Transporter	15.8	6.3	1.7	--	30,071
Power Line Right-of-Way	4.0				
Total	311.5	68.4	33.6	12.6	1,277,768

Functional Assessment

The principal values of the wetlands impacted by the ASRM infrastructure are biotic and hydrologic in character. The wetlands rate low for socio-cultural values due to restricted access, lack of navigable water, restrictions on hunting, and dominance of the pine plantation. Economic values are principally those of pine plantation forestry. Such forestry is ubiquitous in the region and the acreage removed from production would be minimal in a regional context.

The primary biological function of the pine flatwood is as wildlife habitat. However, forest management has converted what appears to be a previous hardwood or hardwood-pine habitat into monotypic pine. This judgement is based on the presence of hardwood regeneration beneath the pine canopy. An additional habitat function found in the pine flatwood forest is the support of pitcher plant bogs (Esher and Bradshaw 1988). These bogs are unique habitats (Folkerts 1982) that have been adversely impacted by forestry management, both by ditching and over-planting of pine.

Similarly, the planting of pine in swales has degraded the bottomland hardwood habitat. Wetland hardwood habitats are a declining resource in the southeastern United States (Mitsch and Gosselink 1986), with the consequence of increased impact on wildlife species dependent on hardwood habitat. The result of pine plantation management has been to impair the wildlife function by reducing hardwood (or mixed hardwood-pine) forests. The wildlife value of hardwood wetland is well documented (Wharton et al. 1982, Brinson et al. 1981, Klimas et al. 1981). In particular, the wetland zone most easily supplanted by pine plantation, namely that which borders true upland, has been considered the most valuable as a grazing-foraging system for animals (Wharton et al. 1982). It is in this zone that production of nuts (e.g., acorns) and fruits, berries and seeds is optimal for many preferred wildlife foods. This marginal wetland zone was formerly of much greater ecological importance in the region (Johnson 1987), as well as in the ASRM site. The opportunity for its eventual enhancement as part of ASRM project mitigation is therefore commensurately great.

The principal hydrologic functions of the impacted areas are flood storage and desynchronization of storm flow. The proposed ASRM Static Test Facility is located in the headwaters of the Jourdan River and Pearl River watersheds. The microtopography is undulating, resulting in many storage depressions. Detained runoff provides desynchronous stormflow, as well as subsequent infiltration and subsurface flow to augment aquifer supplies. At present, the ubiquitous drainage ditches at the ASRM site reduce both storage and flow desynchronization.

MITIGATION ACTIONS

A. Avoidance

The ASRM Program represents a multifaceted action including the design, construction and operation of new facilities for the manufacturing and testing of the booster engines for the space shuttle. Various sites through the country were evaluated. Overall site selection was based on environmental and programmatic considerations following federal guidelines including NEPA and the preparation of a programmatic environmental impact statement (NASA 1989). A Record of Decision was signed on April 17, 1989. The Tennessee Valley Authority's Yellow Creek facility, near Iuka, Mississippi has been selected for the manufacturing of the new booster motors. The SSC has been selected for static test firing of the motors.

Once SSC was selected as the site for static test firing of the motors, various sites within the SSC Fee Area were evaluated. Site selection criteria included transportation considerations, safety considerations, property limitations, and environmental effects. The selection of the site was dependent on water access in that the large motors would be transported by barge from the manufacturing facility in Yellow Creek. The program has gone through three iterations to arrive at the final site. The first site was elected by the Contractor (Lockheed/Aerojet) in the proposal stage of the program procurement. After the selection of the successful proposal, the Contractor submitted his site selection to NASA along with 90% site design drawings. In NASA's evaluation of the proposed site, three areas of concern required the site to be relocated. The areas of concern included the unnecessary impact to the bottomland hardwood wetlands of Lion and Wolf Branches, the inefficient use of Fee Area property, and the excessive length of the heavy-duty transport road. In response to those concerns, NASA suggested the second site, which minimized these concerns. The third site was an agreement between NASA and the Contractor after addressing environmental concerns.

The site selected meets the following criteria: minimizes impact to Lion and Wolf Branches, does not impact any existing or known future program plans, maximizes required land use to provide safe distance area, minimizes heavy-duty transport road and its effect upon wetlands, and allows for the maximum use of existing utility corridors and road beds. Overall SSC facility master plan also establishes specific site zones for hazard testing guidelines in order to provide worker safety. Numerous meetings with the US Army Corps of Engineers and other agencies governing wetlands permitting provided information which was utilized in choosing the final site. This site reflects the minimum possible physical and functional impact to wetlands at SSC.

B. Minimization

The buildings for the individual ASRM facilities have been located to minimize the impact to wetland areas. Placement of the individual buildings were as close to existing roadways as possible to insure that a minimum amount of roadway was needed to access the building during the course of normal operations. Parking areas around the buildings were kept to the minimum number of spaces needed by support personnel for the safe testing and operation of the facility during a test period. The original number of parking spaces provided at the Engineering Operations Building was 100 spaces; this number was reduced to 92 resulting in a savings of 8 parking spaces. The original number of parking spaces provided at the Test Control Center was 75 spaces; this number was reduced to 60 resulting in a savings of 15 parking spaces. The parking areas around the Test Control Center and the Engineering Operations Building were thus reduced by a total of 23 parking spaces.

Finish grading elevations on roadways have been set as low as practical to insure the minimum impact to wetland areas, while maintaining adequate safety and drainage design requirements anticipated over the life of the facility. Original concepts established the top of pavement elevation at 30 feet along the lateral access road, and pavement elevations of 30 to 36 feet along Mainline road. The Transporter Road was level, at an elevation of 26 feet, the entire length of roadway. The redesigned roadways were lowered approximately 1 foot to as much as 4 feet, to allow them to follow the existing topography, thereby reducing the amount of fill and significantly reducing the amount of wetland impact. Minimum roadway and shoulder widths are being used, consistent with the safe operation of the type of vehicles anticipated. The lateral access road which services the Test Stand Area was initially located approximately 400 feet west of the Test Stand Area. After further study of the affected upland and wetland locations, this road was moved to utilize as much of the existing roadways and uplands as possible.

The original proposed location of the Test Stand was rejected due to the wetland impacts this location would have on Lion Branch. A second location was rejected because the quantity/distance (QD) interact distance would encroach over the Fee Boundary and into the Buffer Zone which was a violation of SSC Facility Master Plan.

Roadway alternate number 1 was the original route proposed but was rejected for two reasons. Number one was the lack of upland located along this route which would impact a large amount of wetlands. Number two was for quicker access to the Test Stand, Test Stand facilities, Equipment Storage Building or the Dock Area case of emergencies. Roadway alternate number 2 was rejected due to the amount of fill which would be required to cross the various

drainage depressions located along this access. Combined with the lack of existing roadways, which the proposed lateral access road utilizes, the overall fill within wetlands makes this alternate unacceptable. Other alternatives were investigated, such as raising the Test Stand, but were rejected due to the adverse impacts these alternatives would have on the wetlands.

Along with precautions taken during construction such as the use of laydown areas and erosion controls, these actions will insure the minimum amount of wetland disturbance required for construction of the ASRM Static Test Facility.

C. Maintenance

In the general way described elsewhere creation of a large opening in the forest (the Test Range) would offer new habitat for those plants and animals requiring it, and habitat enhancement for those capable of exploiting it periodically. Although these organisms would benefit from such an opening even if it were managed with no consideration for their welfare, its effectiveness as wildlife habitat could be increased with relatively little additional cost. For instance, giving the test range scalloped rather than straight edges would add length to the productive field-forest interface. Burning or cutting the field selectively to leave isolated clusters of relatively mature growth (e.g. briar patches with an occasional tall shrub) would augment the cover needed by many small animals and provide lookout, hunting, or singing perches for others. The edge itself should provide a shrubby transition zone of 50 to 100 feet between the field and forest proper. In all cases, native species will be favored over exotics.

The area around the Deflector Ramp will be designed so that all rainfall that strikes the Deflector Ramp will be collected to help maintain water quality. This collected rainfall will then flow through grasslined channels at a very low velocity (e.g. less than 3 feet per second). The grass lining and the slow velocity will act as a filter. The water will be collected in a containment pond. This containment system will be designed to allow settlement of waterborne solids that may remain after the grass-lined channels. The containment system will be sized to allow the first 3.8 inches of rainfall to be collected. This quantity of rainfall represents the 1-hour, 25-year event. The pond will be designed to allow any rainfall greater than 3.8 inches to bypass the containment system by overtopping the channels leading to the containment area. An ongoing monitoring of the depth of accumulated sediment will be made quarterly. When the depth of the accumulated sediment equals one-half the depth of the containment pond, the sediment will be removed and disposed of by placing in an existing spoil area.

D. Compensation

Compensation for the 68.4 acres of fill will take three forms:

- o restoration of the hydrologic functions by filling ditches in the flatwoods, and creation of short berms across drainage swales;
- o restoration of bottomland hardwood forest cover (for wildlife habitat) to the flatwoods by discontinuing pine plantation management; and
- o enhancement of the unique pitcher plant bog habitat by discontinuing pine plantation management.

Each of these items can be accomplished in the vicinity of the ASRM Static Test Facility and the Jourdan River and Pearl River watersheds.

Reversing the influence of pine plantation forest management on the flatwoods, will result in succession to bottomland hardwoods. The bottomland swales will expand in width. This will be accomplished by filling in the drainage ditch system within the ASRM site. One area identified for restoration is the area bounded on the north by Standby Road, on the west by Mainline Road, on the east by Ruffin Road and on the south by development. This flatwood is presently a slash pine plantation with a hardwood component and understory that will naturally succeed to hardwoods. Allowing this succession and increasing the wetlands of this site by filling the drainage ditches will increase wildlife habitat diversity and food supply.

In the bottomland drainage swales throughout the flatwoods, berms will be constructed perpendicular to flow (Mitchell and Newling 1986). These berms are to be 1 to 3 feet high and located at the appropriate topography to form shallow pools in the spring and following large storm events. Probable locations will be along drainageways leading to Lion and Wolf Branches. These will work in conjunction with the filling of ditches to mitigate for the loss of flood storage and flow desynchronization. The final location and pool acreage will be based on detailed topographic mapping.

Pine plantation forest management should be modified in the vicinity of the pitcher plant bogs. These areas should be burned frequently enough to kill the invading shrubs and maintain these open and unique habitats. Fire management should be coordinated with the SSC forest management plan (SEC, Inc. 1989). Harvesting of mature trees can still occur on the flatwood and areas around the pitcher plant bogs, provided no soil is eroded into the bogs. Some large trees and snags should be left for wildlife food and cover. Commercial forestry should be a secondary use of these

areas. They should be managed for wildlife and botanical values; pine planting and drainage ditching are to be abandoned.

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Attachment A-1

FLORISTIC ANALYSES

For each of the proposed areas of major direct impact the vegetation was described within sample plots. For efficiency, the widely used US Army Corps of Engineers method of nested circular plots was employed: percent cover for each herb and seedling species within a 5-foot radius, for each species of shrub, sapling and liana within 15 feet, and basal area of each tree species within 30 feet. With the exception of the Dock Area, each major impact site was sampled with at least 5 of these circular plots, thus providing a measure of frequency (spatial distribution) in addition to cover. The Dock Area's configuration required plots of irregular shape, with corresponding adjustments to plot size as well. In each area of extensive and roughly equidimensional impact, the five replicate plots were located in a "domino" cluster, one at each cardinal point of the compass 100 feet from the fifth and central plot. In the case of the Transporter Road, with its linear impact across bottomland hardwood habitat, the five replicates were strung out 275 feet apart along the axis of the proposed alignment. At points of lesser impact elsewhere in the proposed transport and utilities corridor, a single circular plot was located: one at the lowest point of the proposed lateral access road beside the pipeline, and one each at Lion Branch and Wolf Branch where these are crossed by Mainline Road.

TABLE I-1. FLORISTIC DATA FOR ENGINEERING OPERATIONS BUILDING (n=5).

PLANT	HERB			SHRUB			SAMPLING			VINE			TREE		
	AVERAGE % COVER	FREQ.	AVERAGE % COVER	AVERAGE % COVER	FREQ.	AVERAGE % COVER	AVERAGE % COVER	FREQ.	AVERAGE % COVER	AVERAGE % COVER	FREQ.	AV. BASAL AREA (sq. ft)	FREQ.		
<i>Acer rubrum</i>				0.2	0.2										
<i>Andropogon glomeratus</i>	0.4	0.2													
<i>Berchemia scandens</i>									0.2		0.2				
<i>Bignonia capreolata</i>	0.1	0.2							0.4		0.2				
<i>Carex</i> sp.	+	0.2													
Compositae	+	0.4													
<i>Ilex glabra</i>				0.6	0.2										
<i>Ilex opaca</i>	0.6	0.6		1.8	0.8										
<i>Ilex vomitoria</i>	1.2	0.4		6.0	0.8										
<i>Magnolia virginiana</i>				5.0	0.4										
<i>Myrica cerifera</i>	2.0	0.6		10.8	0.6										
<i>Nyssa sylvatica sylvatica</i>													0.2	0.4	
<i>Panicum virgatum</i>	0.2	0.2													
<i>Pinus elliotii</i>				0.2	0.2								4.2	1.0	
<i>Quercus nigra</i>				0.6	0.2										
<i>Rhus copallina</i>				0.8	0.4										
<i>Rubus argutus</i>	8.4	0.6		54.0	1.0										
<i>Smilax laurifolia</i>															
<i>Taxodium ascendens</i>				0.2	0.2				0.6		0.6		0.9	1.0	
<i>Vitis rotundifolia</i>									2.6		0.6				
									0.3		0.4				
Total average % cover	12.9		80.2			2.6		1.5							

"+" indicates presence with <1% area cover

TABLE 1-2. FLORISTIC DATA FOR TEST CONTROL CENTER (n=5).

PLANT	HERB		SHRUB		SAPLING		VINE		TREE	
	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AV. BASAL AREA (sq. ft)	FREQ.
<i>Acer rubrum</i>			1.2	0.2	2.0	0.2				
<i>Aronia arbutifolia</i>			0.2	0.2						
<i>Ilex coriacea</i>	0.2	0.2	7.0	0.6						
<i>Ilex glabra</i>	5.4	1.0	20.0	0.4						
<i>Ilex myrtifolia</i>			1.2	0.2						
<i>Ilex opaca</i>	0.2	0.2	8.8	0.6	19.0	0.6			0.1	0.4
<i>Ilex vomitoria</i>			11.0	0.4						
<i>Magnolia virginiana</i>			1.4	0.2					0.04	0.2
<i>Myrica cerifera</i>	0.8	0.4	10.0	0.8						
<i>Nyssa sylvatica sylvatica</i>			3.6	0.4	8.0	0.8			0.4	0.6
<i>Osmanthus americanus</i>	0.2	0.2	0.8	0.2						
<i>Persea palustris</i>			0.2	0.2						
<i>Pinus elliotii</i>	+	0.2			1.0	0.2			4.3	1.0
<i>Rubus argutus</i>			3.0	0.2						
<i>Smilax smallii</i>	+	0.2					1.0	0.2		
<i>Smilax glabra</i>							2.2	0.6		
<i>Symplocos tinctoria</i>	+	0.2					0.8	0.4		
<i>Vitis rotundifolia</i>										
Total average % cover	6.8		68.4		30.0		4.0			

"+" indicates presence with <1% area cover

TABLE 1-3. FLORISTIC DATA FOR EQUIPMENT STORAGE BUILDING AND TEST STAND AREA (n=5).

PLANT	HERB			SHRUB			VINE			TREE	
	AVERAGE % COVER	FREQ.	AVERAGE % COVER	AVERAGE % COVER	FREQ.	AVERAGE % COVER	AVERAGE % COVER	FREQ.	AV. BASAL AREA (sq. ft.)	FREQ.	FREQ.
<i>Acer rubrum</i>	0.2	0.4	9.4	0.4	0.2				0.04	0.2	
<i>Arundinaria gigantea</i>	0.8	0.4	11.0		0.2						
<i>Ralduina uniflora</i>	+	0.2					0.4	0.2			
<i>Bignonia capreolata</i>											
<i>Carex</i> sp.	0.4	0.2									
<i>Eriocaulon</i> sp.	0.6	0.2									
<i>Hypericum brachyphyllum</i>	0.2	0.2									
<i>Ilex coriacea</i>	1.0	0.2	16.0		0.6						
<i>Ilex glabra</i>	1.0	0.2	10.0		0.2						
<i>Ilex opaca</i>	0.2	0.4							0.02	0.2	
<i>Ilex vomitoria</i>	0.2	0.2	3.4		0.6						
<i>Magnolia virginiana</i>	0.2	0.2	0.4		0.4	1.0		0.2	0.04	0.2	
<i>Myrica cerifera</i>	0.6	0.2	8.4		0.6	4.0		0.2	0.1	0.4	
<i>Nyssa sylvatica sylvatica</i>			2.0		0.2						
<i>Panicum virgatum</i>	0.6	0.2									
<i>Pinus elliotii</i>						2.8		0.8	3.4	1.0	
Poaceae	1.0	0.4									
<i>Quercus laurifolia</i>						2.0		0.2			
<i>Rhus toxicodendron</i>	7.2	0.6					7.4	0.4			
<i>Rubus argutus</i>	0.6	0.4									
<i>Sarracenia psittacina</i>	0.2	0.2									
<i>Smilax laurifolia</i>							3.0	0.2			
<i>Woodwardia areolata</i>	0.2	0.6									
Total average % cover	15.2		60.6			10.2					
									10.8		

"+" indicates presence with <1% area cover

TABLE I -4. FLORISTIC DATA FOR TEST RANGE, INCLUDING DEFLECTION RAMP AREA (n=5).

PLANT	HERB		SHRUB		SAPLING		VINE		TREE	
	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AV. BASAL AREA (sq. ft)	FREQ.
<i>Andropogon glomeratus</i>	0.2	0.2								
<i>Andropogon scoparius</i>	+	0.2								
<i>Aronia arbutifolia</i>	0.2	0.4								
<i>Eriocaulon decangulare</i>	1.0	0.2								
<i>Hypericum brachyphyllum</i>	0.2	0.2								
<i>Ilex coriacea</i>			20.2	0.8						
<i>Ilex glabra</i>	14.0	0.6	30.2	0.8						
<i>Lycopodium alopecuroides</i>	0.4	0.4								
<i>Magnolia virginiana</i>			2.0	0.4	1.0	0.2				
<i>Nyssa sylvatica sylvatica</i>			1.0	0.2	4.0	0.6			0.5	0.8
<i>Osmunda regalis</i>	+	0.2								
<i>Persea palustris</i>	+	0.4	0.8	0.4						
<i>Pinus elliotii</i>	+	0.2	0.2	0.2	1.0	0.2			5.0	1.0
<i>Pinus taeda</i>										
Poaceae	3.2	0.6								
<i>Quercus laurifolia</i>			1.0	0.2						
<i>Rhus toxicodendron</i>	+	0.2								
<i>Rhynchospora</i> sp.	+	0.2								
<i>Smilax rotundifolia</i>							1.0	0.2		
<i>Smilax tamnoides</i>							1.0	0.2		
<i>Vaccinium fuscum</i>	0.2	0.2								
<i>Woodwardia areolata</i>	+	0.2								
Total average % cover	19.4		55.4		6.0		2.0			

"+" indicates presence with <1% area cover

TABLE 11-5(1). FLORISTIC DATA FOR DOCK AREA, LEVEE BANK TOWARD ACCESS CANAL (n=1).

PLANT	HERB			SHRUB			SAPLING			VINE			TREE		
	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AV. BASAL AREA (sq. ft)	FREQ.	
<i>Acer rubrum</i>					5.0										
<i>Andropogon glomeratus</i>	1.0														
<i>Andropogon scoparius</i>	50.0														
<i>Baccharis halimifolia</i>					5.0										
<i>Erianthus giganteus</i>	4.0														
<i>Ilex vomitoria</i>					2.0										
<i>Myrica cerifera</i>					50.0										
<i>Pinus alliotii</i>					1.0										
Poaceae	30.0														
<i>Rhus copallina</i>	1.0														
<i>Rubus argutus</i>	2.0				2.0										
<i>Rubus trivialis</i>	40.0														
<i>Salvia lyrata</i>	1.0														
<i>Smilax laurifolia</i>											1.0				
<i>Zizaniopsis miliacea</i>	1.0														
Total average % cover	130.0				65.0						1.0				

"±" indicates presence with <1 area cover

TABLE I-5(2). FLORISTIC DATA FOR DOCK AREA, LEVEE BANK AWAY FROM ACCESS CANAL. (n=1).

PLANT	HERB		SHRUB		SAPLING		VINE		TREE	
	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AV. BASAL AREA (sq. ft)	FREQ.
<i>Acer rubrum</i>			3.0							
<i>Andropogon glomeratus</i>	5.0									
<i>Andropogon scoparius</i>	5.0									
<i>Campsis radicans</i>							1.0			
<i>Ilex coriacea</i>			3.0							
<i>Ilex vomitoria</i>			25.0							
<i>Magnolia virginiana</i>			1.0							
<i>Myrica carifera</i>			10.0							
<i>Persea palustris</i>			4.0							
<i>Pinus elliotii</i>			5.0							
Poaceae		10.0								
<i>Prunus serotina</i>			2.0							
<i>Quercus laurifolia</i>			2.0							
<i>Quercus nigra</i>			1.0							
<i>Rhus copallina</i>			3.0							
<i>Rhus toxicodendron</i>							10.0			
<i>Rubus argutus</i>			5.0							
<i>Rubus trivialis</i>			7.0							
<i>Salvia lyrata</i>		3.0								
<i>Symplocos tinctoria</i>			1.0							
Total average % cover	23.0		72.0				11.0			

"+" indicates presence with <1 area cover

TABLE 1-5(3). FLORISTIC DATA FOR DOCK AREA, DEFORESTED AREA AND DITCH (n=1).

PLANT	HERB			SHRUB			SAPLING			VINE			TREE		
	AVERAGE % COVER	FREQ.	AVERAGE % COVER	AVERAGE % COVER	FREQ.	AVERAGE % COVER	AVERAGE % COVER	FREQ.	AVERAGE % COVER	AVERAGE % COVER	FREQ.	AV. BASAL AREA (sq. ft)	FREQ.		
<i>Hypericum brachyphyllum</i>	+														
<i>Ilex coriacea</i>			55.0												
<i>Ilex glabra</i>	1.0			5.0		5.0									
<i>Magnolia virginiana</i>															
<i>Myrica cerifera</i>	1.0														
<i>Nyssa sylvatica sylvatica</i>															
<i>Osmanthus americanus</i>			10.0			20.0						0.3			
<i>Persea palustris</i>	1.0														
<i>Pinus elliotii</i>	+		2.0												
<i>Quercus laurifolia</i>				5.0								1.2			
<i>Quercus lyrata</i>			3.0												
<i>Quercus nigra</i>			1.0												
<i>Saxifraga laurifolia</i>															
<i>Symplocos tinctoria</i>										5.0					
<i>Vaccinium fuscatum</i>	6.0		10.0												
<i>Woodwardia areolata</i>	1.0														
Total average % cover	10.0		86.0			30.0			5.0						

"+" indicates presence with <1% area cover

TABLE 1-6. FLORISTIC DATA FOR TRANSPORTER ROAD BOTTOMLAND HARDWOOD WETLAND (n=5).

PLANT	HERB			SHRUB			SAPLING			VINE			TREE	
	AVERAGE % COVER	FREQ.	AVERAGE % COVER	AVERAGE % COVER	FREQ.	AVERAGE % COVER	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AV. BASAL AREA (sq. ft)	FREQ.
<i>Acer rubrum</i>				2.0	0.2	2.0	2.0	0.2			0.6	0.4	0.38	0.8
<i>Bignonia capreaolata</i>														
<i>Fraxinus pensylvanica</i>				0.4	0.2	2.4		0.4						
<i>Lyonia lucida</i>	0.4	0.4		1.8	0.8									
<i>Magnolia virginiana</i>	0.2	0.2		1.0	0.4									
<i>Nyssa sylvatica sylvatica</i>				6.4	0.6	34.0		1.0					0.26	0.4
<i>Pinus elliotii</i>													2.2	1.0
<i>Quercus laurifolia</i>				0.4	0.2	11.0		0.6					0.04	0.2
<i>Quercus nigra</i>						1.0		0.2					2.2	1.0
<i>Rhododendron viscosum</i>				2.6	0.8								0.56	0.4
<i>serrulatum</i>														
<i>Smilax laurifolia</i>											0.4	0.2		
<i>Symplocos tinctoria</i>	+	0.4	10.2		0.6	11.0		0.8					0.2	0.6
<i>Taxodium ascendens</i>						3.0		0.6					0.4	1.0
Total average % cover	0.6		24.8			64.4					1.0			

"+" indicates presence with <1% area cover

TABLE 1.-7. FLORISTIC DATA FOR LATERAL ACCESS ROAD ALONG CURRENT PIPELINE RIGHT-OF-WAY (n=1).

PLANT	HERB			SHRUB			SAPLING			VINE			TREE		
	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AV. BASAL AREA (sq. ft)	FREQ.	
<i>Ilex coriacea</i>	+				1.0										
<i>Magnolia virginiana</i>													0.1		
<i>Nyrica cerifera</i>	+				15.0										
<i>Nyssa sylvatica sylvatica</i>							5.0								
<i>Pinus elliotii</i>													0.5		
Poaceae	+												7.0		
<i>Quercus laurifolia</i>	+														
<i>Taxodium ascendans</i>													0.26		
Total average % cover					16.0		5.0								

"+" indicates presence with <1% area cover

TABLE 1-8. FLORISTIC DATA FOR LION BRANCH CROSSING OF HAINLINE ROAD (n=1).

PLANT	HERB			SAPLING			VINE		TREE	
	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AV. BASAL AREA (sq. ft)	FREQ.
<i>Carex</i> sp.	2.0									
<i>Lyonia lucida</i>	10.0		20.0							
<i>Magnolia virginiana</i>										
<i>Nyssa sylvatica sylvatica</i>					30.0				0.2	
<i>Rhododendron viscosum</i>									7.3	
<i>Sarrulatum</i>										
<i>Ilex amelanchier</i>			30.0							
<i>Rhus toxicodendron</i>			40.0							
<i>Saxifraga laurifolia</i>							5.0			
							10.0			
Total average % cover	12.0		90.0		30.0		15.0			

"+" indicates presence with <1% area cover

TABLE 1-9. FLORISTIC DATA FOR WOLF BRANCH CROSSING OF MAINLINE ROAD (n=1).

PLANT	HERB		SHRUB		SAPLING		VINE		TREE	
	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AVERAGE % COVER	FREQ.	AV. BASAL AREA (sq. ft)	FREQ.
<i>Clethra alnifolia</i>	3.0		1.0							
<i>Lyonia lucida</i>	2.0									
<i>Magnolia virginiana</i>			5.0							
<i>Nyssa sylvatica biflorum</i>	1.0				10.0				2.0	
<i>Pinus elliotii</i>									5.5	
<i>Quercus laurifolia</i>			5.0						1.5	
<i>Quercus nigra</i>									0.4	
<i>Rhus toxicodendron</i>							2.0		0.2	
<i>Saxilax laurifolia</i>							5.0			
Total average % cover	6.0		11.0		10.0		7.0			

"+" indicates presence with <1% area cover

Attachment A-II

WILDLIFE HABITAT EVALUATION

The approach taken here to wildlife habitat evaluation steers a middle course between the unsystematic generalizations born of anecdote and inventory on the one hand, and on the other the precise, exhaustive calculations of Habitat Suitability Indices for selected individual species, as described in the US Fish and Wildlife Service Habitat Evaluation Procedures (HEP) (USFWS 1980). Normandeau Associates Inc. adopted the method described by the USFWS in Flood et al. (1977), which assigns key game species to ecologically similar groups sharing a reasonably predictable degree of dependence on different habitats (forest, field, and river). These groups thereby serve to indicate the overall capacity of each study site to support a variety of typical fauna, on a scale of 1 (lowest capacity) to 10 (highest capacity). Habitat quality comparisons may then be made among all study sites for the named species groups (evaluation elements), and by extension for many other species known to have similar affinities.

The advantage of this method is that habitat is evaluated for many species of interest in a relatively brief time, which is summarized by simple numbers for easy comparability. However, grouping species disregards the fact that no two species have exactly the same habitat needs and preferences. What is an optimal habitat component for one species may not be so for another in the sample group. The number assigned as a rank for this habitat component necessarily takes both species into consideration, which forces a compromise. The effect of habitat evaluation ranking by species groups is therefore to diminish use of the extremes of the scale. The overall ranking of each habitat type will consequently center on the middle range of values (4.0-6.9) more often than may be appropriate for any given species. Notwithstanding this tendency, serviceable comparisons have still been made here among the different sites, based on the relative ranking within the somewhat reduced numerical range.

For the purposes of this study, the evaluation elements (species groups) have been defined as follows:

Forest Game:	White-tailed deer Wild turkey	Odocoileus virginianu Meleagris gallopavo
Upland Game:	Bobwhite quail Eastern cottontail rabbit	Colinus virginianus Syvilagus floridanus
Tree Squirrels:	Eastern gray squirrel Eastern fox squirrel	Sciurus carolinensis Sciurus niger
Terrestrial Furbearers:	Raccoon Opossum Striped skunk Gray fox cinereoargenteus	Procyon lotor Didephis marsupiali Mephitis mephitis Urocyon
Aquatic Furbearers: Beaver	Muskrat Castor canadensis	Ondatra zibethicus
Waterfowl:	Wood Duck	Air sponsa

TABLE II-1 SUMMARY WILDLIFE HABITAT RANKING BY SPECIES GROUP AND IMPACT ZONE.

EVALUATION ELEMENT	ENGINEERING OPERATIONS BUILDING	TEST CONTROL CENTER	DOCK AREA	TEST STAND/ DEFLECTOR RAMP		TEST RANGE	SOUTH TRANSPORTER ROAD
				Forest	River		
Forest game	5.7	6.1	5.3	NA	5.1	6.1	3.5
Tree squirrels	4.0	4.0	4.7	NA	2.0	3.6	4.8
Terrestrial furbearers	5.6	5.1	4.9	NA	3.4	4.2	3.3
Upland game	4.4	4.9	5.3	NA	2.4	5.3	1.5
Waterfowl	3.0	2.9	3.9	3.1	2.5	3.1	4.9
Aquatic furbearers	NA	NA	4.7	4.8	NA	NA	3.0

APPENDIX B

Justification for the Mixing Height Used in INPUFF 2.3 Dispersion Modeling

APPENDIX B

JUSTIFICATION FOR THE MIXING HEIGHT USED IN INPUFF 2.3 DISPERSION MODELING

MIXING HEIGHTS

Definition: The mixing height is defined as the depth of the atmospheric mixing layer. The mixing layer is the region of the lower atmosphere which is continually *mixing* vertically due to turbulence. The turbulence is induced by winds, solar heating, and roughness features on the Earth's surface (i.e., hills and mountains). Generally, as the sun warms the air during the day, the mixing heights increase. Therefore, afternoon mixing heights are generally higher than morning mixing heights.

Mixing heights may change from day to day depending upon the weather. A low-level temperature inversion such as the inversions which exist over Los Angeles during the summer, is an example of a low mixing height. Fair weather in southern Mississippi is often characterized by vigorous vertical mixing creating high mixing heights.

The degree of dispersion of pollutants in the atmosphere is different for pollutants emitted below the mixing height than it is for pollutants emitted above the mixing height. When pollutants are emitted into the mixing layer (e.g., automobile exhaust and industrial stack emissions), the atmospheric turbulence tends to disperse the pollutants throughout the mixing layer. The low mixing height in Los Angeles during the summer traps the pollutants near the ground and provides only a small volume for the pollutants to disperse into. As a result, the pollutant concentrations in Los Angeles are high. When an inversion does not exist over Los Angeles, the mixing height is much higher, the pollutants are dispersed throughout a larger volume, and the air concentrations are lower.

The atmosphere above the mixing height is generally less turbulent and vertical mixing is suppressed. When pollutants are emitted above the mixing height, they are slowly dispersed and do not tend to mix with the air below. These pollutants tend to remain above the mixing height and, therefore, the ground-level concentrations are lower than if the pollutants were emitted below the mixing height.

MIXING HEIGHTS AND ASRM EXHAUST PLUME DISPERSION

The ASRM exhaust plume is predicted to rise to an elevation (plume centerline) of 13,380 feet before it begins to disperse substantially. The plume is also predicted to expand into a cloud which is approximately 3.8 miles in diameter. Since half of the plume will be below the plume centerline elevation of 13,380 feet, the base of the plume will have an elevation of roughly 3,000 feet. For low mixing heights (< 3000 feet), the plume will be entirely above the mixing layer (Figure B-1). In such cases, since the vertical dispersion is slow above the

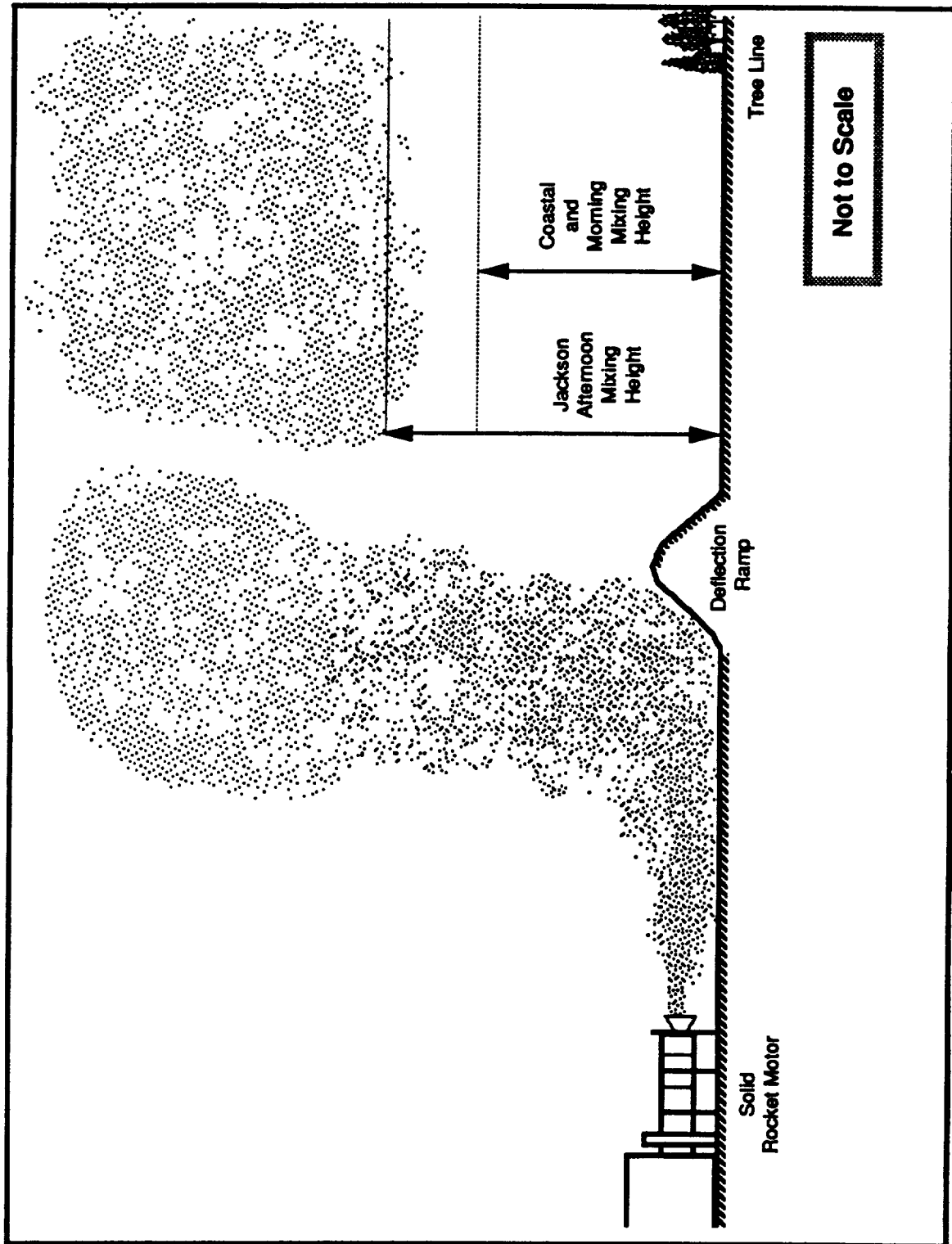


Figure B-1. Schematic of ASRM exhaust plume and Jackson and Coastal mixing heights.

mixing height, the plume will not mix substantially with the air near the ground and the ground-level concentrations will be very low. For higher mixing heights (>3000 feet), part of the plume may be below the mixing height and part of it above the mixing height (Figure B-1). That part of the plume which is below the mixing height will be mixed with air near the ground, affecting ground-level concentrations. However, the part of the plume which remains above the mixing height will not mix with the air near the ground and will not contribute to the ground-level concentrations. Therefore, for a given final plume elevation, higher mixing heights will tend to *increase* ground-level concentrations and lower mixing heights will tend to *decrease* the ground-level concentrations.

MIXING HEIGHTS USED FOR THE INPUFF 2.3 DISPERSION MODELING

The annual average afternoon mixing heights vary with location (Figure B-2). In Mississippi, the mixing heights increase with distance inland. The annual average morning and afternoon mixing heights for Jackson, MS; Burrwood, LA; Lake Charles, LA; and Brownsville, TX are given in Table B-1. Jackson, MS is further north than Lake Charles, LA and, therefore, has a higher mixing height.

The afternoon mixing height for Jackson, MS was used in the INPUFF 2.3 dispersion modeling for two reasons. First, the predominant upper-level winds around Stennis Space Center (SSC) blow from west to east or from southwest to northeast (Figure B-3). Therefore, the plume will usually be blown towards areas of higher mixing heights. Second, higher mixing heights produce higher ground-level concentrations than lower mixing heights. Using the higher Jackson, MS mixing height, therefore, is a conservative assumption.

SUMMARY

The Jackson, MS average afternoon mixing height of 4,261 feet is approximately 1,000 feet higher than the predicted base of the exhaust plume when it has reached its final centerline elevation. The dispersion model, therefore, predicts measurable ground-level concentrations for the gases and particles in the plume. If the dispersion model were run with mixing heights below 3,000 feet such as might be expected near the coast or in the morning, the ground-level concentrations would be much lower and may be zero in some cases. For low mixing heights, the plume would remain above the mixing layer and would not mix appreciably with the air near the ground.

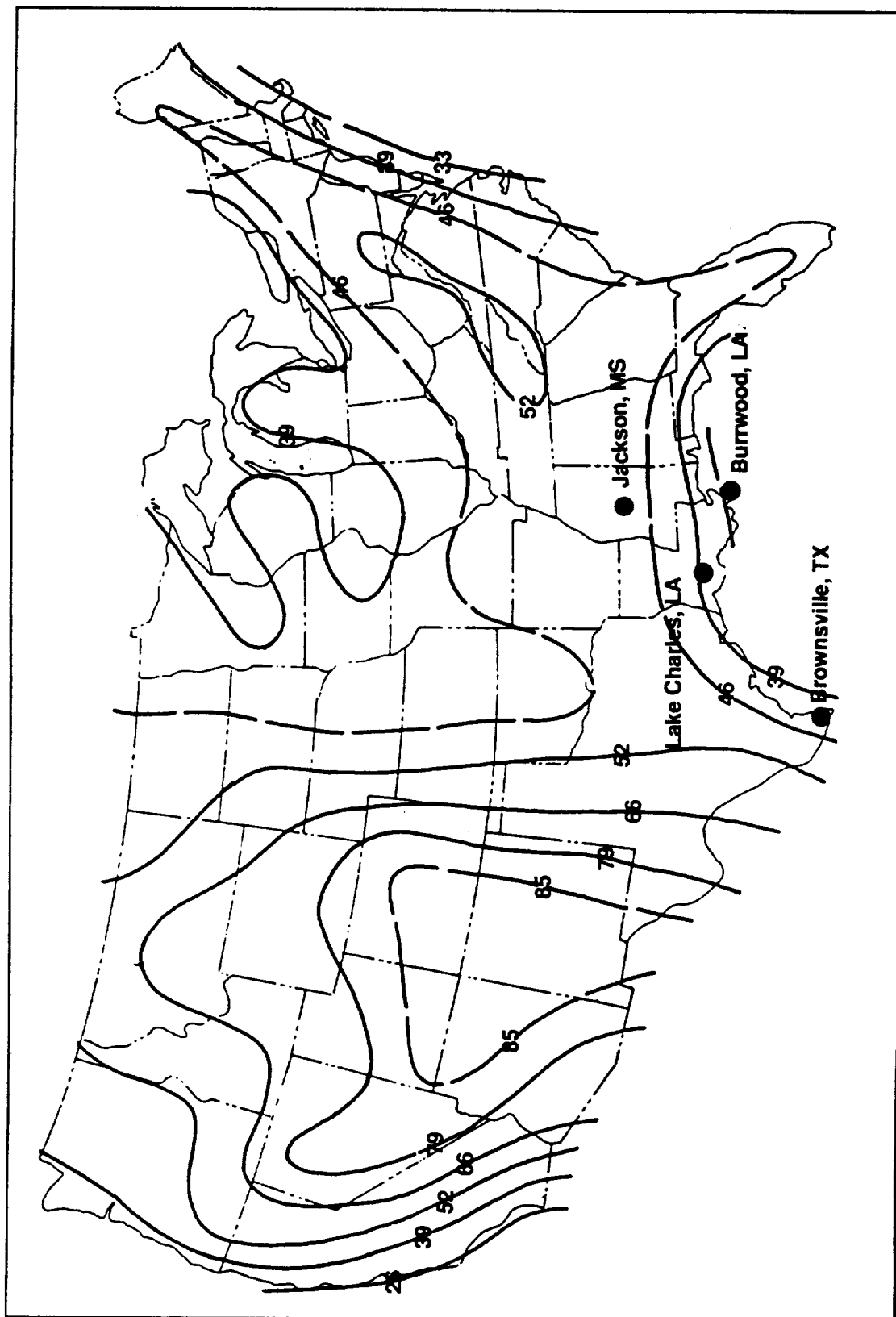


Figure B-2. Isopleths of mean annual afternoon mixing heights. Isopleths are in hundreds of feet (ft x 100). Locations of the four cities in Table B-1 are shown. (Source: EPA 1972)

Table B-1. Annual average morning and afternoon mixing heights.

Location	Morning Mixing Height (feet)	Afternoon Mixing Height (feet)
Jackson, MS	1,235	4,621
Burrwood, LA	2,958	3,060
Lake Charles, LA	1,246	3,811
Brownsville, TX	1,971	4,146

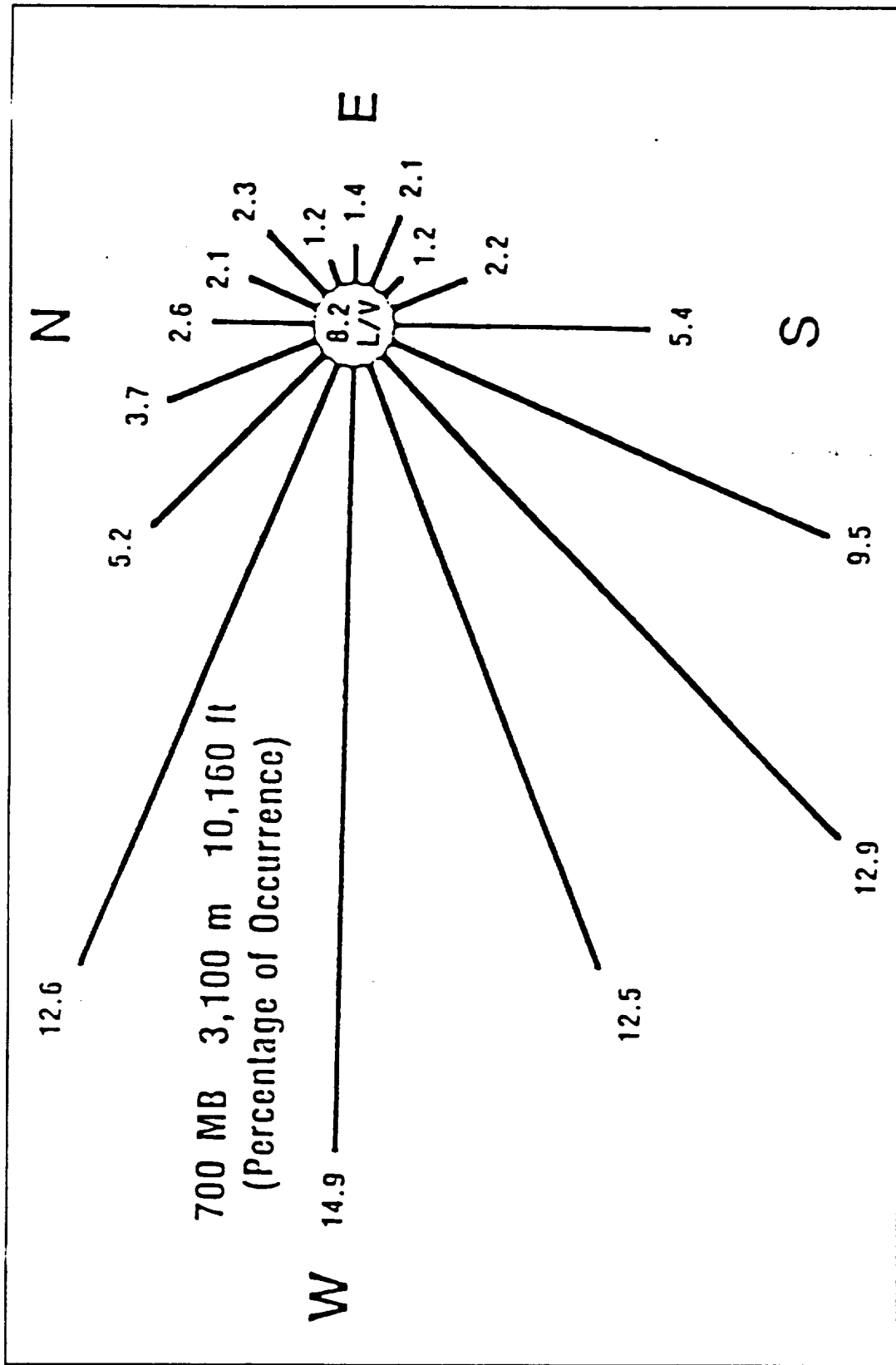


Figure B-3. Annual wind direction diagram (wind rose) for Stennis Space Center at 10,160-foot elevation. The diagram displays the percentage of time the wind blows in any one of 16 directions. The diagram shows that the predominant upper-level wind direction at Stennis is from the west and southwest. L/V indicates light and variable wind directions. (Source: NASA 1990C)

REFERENCES

EPA (Environmental Protection Agency). 1972. Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States. George C. Holzworth, Division of Meteorology, Office of Air Programs, Research Triangle Park, NC.

APPENDIX C

Sample Calculation of Surface Water pH

APPENDIX C

SAMPLE CALCULATION OF SURFACE WATER pH

RAINFALL DATA

Rainfall: 2 cm
 Raincloud surface area: 124 sq km
 Rainfall volume: 2.48×10^9 liters
 Rain pH: 2.9
 Moles H^+ /liter rain: 1.26×10^{-3}
 Moles H^+ /rain event: 3.12×10^6

SURFACE WATER DATA

(estimated for calculation purposes)

Surface water depth: 15.2 cm (6 inches)
 Surface water area: 124 sq km
 Surface water volume: 1.9×10^{10} liters

SITE-SPECIFIC SURFACE WATER DATA

<u>PARAMETERS/ PREDICTIONS</u>	<u>NORTHERN BRANCH DEVIL'S SWAMP SAMPLE SITE</u>	<u>EAST PEARL RIVER SAMPLE SITE</u>	<u>GEO MEAN ALL SITES</u>
ALKALINITY			
Alkalinity (mg $CaCO_3$ /L)	5	12	24.7
Moles H^+ /L neutralized at this alk.	1.0×10^{-4}	2.4×10^{-4}	4.9×10^{-4}
Total moles H^+ neutralized surface water	1.9×10^6	4.6×10^6	9.4×10^6
pH			
pH (sampled)	5.8	6.3	6.1
Moles H^+ /L	1.58×10^{-6}	5.0×10^{-7}	7.9×10^{-7}
Total moles H^+ surface water	3.00×10^4	9.50×10^3	1.50×10^4
PREDICTIONS			
Excess moles H^+ not neutralized	1.22×10^6	(no excess)	(no excess)
Final moles H^+ /L in surface water after deposition	6.6×10^{-5}	5.0×10^{-7}	7.9×10^{-7}
pH (predicted Case 2)	4.2	6.3	6.1

Sample Calculations (Northern branch of Devil's Swamp data used as example)

■ **Rainfall Volume -**

$$2 \text{ cm} \times \frac{1 \text{ m}}{100 \text{ cm}} \times \frac{1 \text{ km}}{1,000 \text{ m}} = 2 \times 10^{-5} \text{ km}$$

$$2 \times 10^{-5} \text{ km} \times 124 \text{ km}^2 \times \frac{1 \times 10^9 \text{ m}^3}{1 \text{ km}^3} \times \frac{1,000 \text{ L}}{\text{m}^3} = 2.48 \times 10^9 \text{ L rain}$$

■ **Moles hydrogen ion/liter rain -**

$$\text{pH} = -\log [\text{H}^+] \quad [\text{H}^+] = \text{antilog} - \text{pH}$$

$$\text{antilog} - 2.9 = 1.26 \times 10^{-3} \text{ moles H}^+/\text{L rain}$$

■ **Total moles hydrogen ion/rain event -**

$$1.26 \times 10^{-3} \text{ moles H}^+/\text{L} \times 2.48 \times 10^9 \text{ L} = 3.12 \times 10^6 \text{ moles H}^+ (\text{rain event})$$

■ **Surface water volume -**

$$6 \text{ in} \times \frac{2.54 \text{ cm}}{\text{in}} \times \frac{1 \text{ m}}{100 \text{ cm}} \times \frac{1 \text{ km}}{1,000 \text{ m}} \times 124 \text{ km}^2 \times \frac{1 \times 10^9 \text{ m}^3}{1 \text{ km}^3} \times \frac{1,000 \text{ L}}{\text{m}^3} = 1.9 \times 10^{10} \text{ L}$$

■ **Moles hydrogen ion/liter neutralized at alkalinity (5) -**

$$\frac{5 \text{ mg CaCO}_3}{\text{L}} \times \frac{1 \text{ g CaCO}_3}{1,000 \text{ mg}} \times \frac{1 \text{ mole CaCO}_3}{100 \text{ g CaCO}_3} \times \frac{2 \text{ mole H}^+ \text{ neut.}}{1 \text{ mole CaCO}_3}$$

$$= 1 \times 10^{-4} \text{ moles H}^+/\text{L neutralized at alk} = 5$$

■ **Total moles hydrogen ion neutralized surface water -**

$$1 \times 10^{-4} \text{ moles H}^+/\text{L} \times 1.9 \times 10^{10} \text{ L} = 1.9 \times 10^6 \text{ moles H}^+ \text{ neutralized}$$

- Moles hydrogen ion/liter in surface water =

$$\text{pH} = -\log [\text{H}^+] \quad [\text{H}^+] = \text{antilog} - \text{pH}$$

$$\text{antilog} - 5.8 = 1.58 \times 10^{-6} \text{ moles H}^+/\text{L surface water}$$

- Total moles hydrogen ion in surface water body =

$$1.58 \times 10^{-6} \text{ moles H}^+/\text{L} \times 1.9 \times 10^{10} \text{ L} = 3.00 \times 10^4 \text{ moles H}^+ \text{ surface water}$$

- Excess moles hydrogen ion not neutralized =

$$\begin{array}{ccc} (3.12 \times 10^6 \text{ moles H}^+) & - & (1.9 \times 10^6 \text{ moles H}^+) = 1.22 \times 10^6 \text{ moles H}^+ \\ \text{(rain)} & & \text{(moles H}^+ \text{ capable of} \\ & & \text{being neutralized by} \\ & & \text{surface water)} \end{array} \quad \text{(not neutralized)}$$

- Final moles hydrogen ion in surface water/liter after deposition =

$$\begin{array}{ccc} 1.22 \times 10^6 \text{ moles H}^+ & + & 3.00 \times 10^4 \text{ moles H}^+ = 1.25 \times 10^6 \text{ moles H}^+ \\ \text{(rain excess H}^+) & & \text{(surface water H}^+) \quad \text{(Total H}^+) \end{array}$$

$$\frac{1.25 \times 10^6 \text{ moles H}^+}{1.9 \times 10^{10} \text{ L}} = 6.6 \times 10^{-5} \text{ moles H}^+/\text{L surface water}$$

- Final pH after deposition =

$$\text{pH} = -\log [\text{H}^+] \quad [\text{H}^+] = 6.6 \times 10^{-5} \text{ moles/L}$$

$$\text{pH} = -\log (6.6 \times 10^{-5}) = 4.18$$

APPENDIX D

Sample Calculation of Rainwater pH

APPENDIX D SAMPLE CALCULATION OF RAINWATER PH

INTRODUCTION TO ACID RAIN

Acid rain is caused when certain kinds of chemicals called *acids* dissolve in the rainwater. Additionally, other chemicals, which react chemically with water to form acids, can dissolve in the rain and cause it to be acidic. When an acid molecule dissolves in water, one or more hydrogen atoms detach from the acid molecule and remain separated in the water. These separated hydrogen atoms are called hydrogen ions and are given the symbol H^+ . The hydrogen ions in the rainwater are responsible for the acidic properties associated with acid rain, and the acidity of the rain is proportional to the concentration of the hydrogen ions in the rainwater.

Acid rain scientists have adopted the chemists' system for expressing the acidity of water: the pH scale. The pH scale describes the concentration of hydrogen ions $[H^+]$ in the water. Technically, pH is defined as the negative logarithm of the hydrogen ion concentration. The scale is logarithmic, so each successive pH unit represents a 10-fold change in the concentration of hydrogen ions. Doubling or halving the acidity, which means doubling or halving the concentration of hydrogen ions, changes the pH by 0.3 units. Water pH ranges from extremely alkaline (pH 14) to extremely acid (pH 0); the neutral point is pH 7.0. All values lower than 7.0 are acidic; all above pH 7.0 are alkaline or basic. The lower the pH, the greater the acidity.

Unpolluted precipitation is commonly assumed to have a pH value of approximately 5.6. This mild acidity is caused by the presence of carbon dioxide in the atmosphere, dissolving in the rainwater and forming carbonic acid (a common acid, caused by carbonation, that is found in soft drinks as well). Natural constituents such as ammonia, soil particles, seaspray, sulphur dioxide, sulphate particles, and volcanic emissions of sulphur dioxide and hydrogen sulphide can increase or decrease the pH of precipitation from 5.6. It is not unusual for a rainwater pH value of between 4 and 5 to occur at remote locations such as the middle of the Pacific Ocean, far removed from human interference (Hibbard 1982). The greatest increase in rainwater acidity, however, is due to manmade pollution. Specifically, the combustion of coal and other fossil fuels produces oxides of sulphur and nitrogen that greatly affect rainwater acidity.

CALCULATION OF RAINWATER PH AT SSC UNDER THE CASE 2 SCENARIO

Under the Case 2 scenario, the HCl gas in the exhaust plume will dissolve into cloud water droplets and subsequently be rained out. The cloud droplets will have natural and manmade chemicals dissolved in them before the HCl is added. The annual average pH of the rain at SSC due to these natural and manmade chemicals is 4.5 (USGS 1989). Any additional acids dissolved in the cloud droplets will increase the acidity (lower the pH).

Since HCl forms an acid when dissolved in water, it will increase the hydrogen ion concentration in the droplet, increasing the acidity (lowering the pH).

The acidity of the rain will be equal to the existing acidity from background sources plus the acidity from the dissolved HCl. As an example, the pH of a rain occurring immediately after testing (Table 4-5) is calculated below.

(1) Calculate the volume of rainwater

Volume (cubic meters) = rain depth (meters) x cloud area (square meters)

$$\rightarrow 2.0 \times 10^6 \text{ m}^3 = 0.02 \text{ m} \times 1.0 \times 10^8 \text{ m}^2$$

$$\rightarrow 2.0 \times 10^6 \text{ m}^3 = 2.0 \times 10^9 \text{ liters}$$

(2) Calculate moles of H^+ from HCl

Moles H^+ = total mass of HCl (g)/36 (g/mole)

$$3,243,055 \text{ moles} = 116,750,000 \text{ g}/36 \text{ g/mole}$$

(3) Calculate concentration of H^+ in rain due to HCl

Concentration H^+ = moles H^+ /rain volume

$$1.6 \times 10^{-3} \text{ moles per liter} = 3,243,055 \text{ moles}/2.0 \times 10^9 \text{ liters}$$

(4) Calculate the concentration of H^+ due to background sources in the rain.

$$\text{Concentration } \text{H}^+ \text{ (moles per liter)} = 10^{-(\text{pH})} \rightarrow 3.16 \times 10^{-5} \text{ moles per liter} = 10^{(4.5)}$$

(5) Calculate total H^+ concentration

Total H^+ concentration = concentration due to HCl + concentration due to background sources

$$\rightarrow 1.6 \times 10^{-3} \text{ moles per liter} = 1.6 \times 10^{-3} \text{ moles per liter} + 3.16 \times 10^{-5} \text{ moles per liter}$$

(6) Calculate final pH of rain

pH = $-\log$ total H^+ concentration

$$2.8 = -\log 1.6 \times 10^{-3}$$

REFERENCES

- Hibbard, W.R. 1982. Acid Precipitation: A Critique of Present Knowledge and Proposed Action. Materials and Society, Vol. 6, pp. 357.
- USGS (U.S. Geological Survey). 1989. Precipitation-Quality Monitoring in Southern Mississippi, 1982-87 U.S. Geological Survey. Open-File Report 89-266.

APPENDIX E

Meteorological Principles Related to ASRM Test Plume Buoyancy and Behavior

APPENDIX E

METEOROLOGICAL PRINCIPLES RELATED TO ASRM TEST PLUME BUOYANCY AND BEHAVIOR

INTRODUCTION

An ASRM will burn 1.206 million pounds of solid fuel in about two minutes. The combustion process will produce an extremely hot exhaust plume (initially 6,000°F) which will rise to high altitudes before stabilizing and dispersing. Several questions have been raised about the behavior of this rising plume in the humid southern Mississippi climate. This section is designed to answer two of the questions on the plume behavior: 1) what effect the humid climate will have on the buoyant rise and dispersion of the plume; and 2) whether this rising plume will create a cumulus cloud and produce acid rain. Before these questions can be adequately answered, some of the concepts used in the study of meteorology must be examined. These questions require an understanding of a few basic properties of gases and moisture in the atmosphere and the processes of cloud and rain formation. The essential meteorological concepts that govern the plume behavior are:

- Concept 1: Pressure and Density in the Atmosphere
- Concept 2: Temperature in the Atmosphere
- Concept 3: Properties of Gases and Moisture in the Atmosphere
- Concept 4: The Rate of Temperature Change with Elevation for Saturated Air
- Concept 5: Cloud Formation
- Concept 6: Rain Formation

Each concept will be explained individually before bringing them together to answer the questions on plume behavior.

CONCEPT 1: PRESSURE AND DENSITY IN THE ATMOSPHERE

The pressure and density of air are related to the elevation in the atmosphere. This relationship between pressure, density, and altitude can be attributed to gravity. The force of gravity draws all matter earthward, even the air, which is often thought of as having almost no substance or weight. However, the molecules of nitrogen, oxygen, water vapor, and the other gases in the atmosphere, like all matter, do have weight and are attracted earthward by gravity. The air molecules in the air at sea-level, New Orleans for example, are squeezed closely together under the weight of the molecules above them. When the air molecules are tightly packed together we say that the air has a high density. The air in higher elevations of the atmosphere, on the other hand, has very few molecules above it; therefore, the molecules are loosely packed together. This air is less dense than the air at

sea-level and so we say it is thin. This is analogous to a helium balloon which rises because helium is less dense than air.

The atmospheric pressure of air at a point on the Earth's surface is the result of the weight of the air molecules above being drawn gravitationally downward. At high elevations, such as Mt. Everest, there are fewer air molecules overhead than there are above the air in New Orleans. Therefore, the atmospheric pressure is lower on Mt. Everest than it is in New Orleans. In other words, atmospheric pressure decreases with increasing elevation.

CONCEPT 2: TEMPERATURE IN THE ATMOSPHERE

The change in atmospheric pressure with altitude is important to understanding the ASRM exhaust plume behavior, because the temperature of a gas is related to its pressure. Gases in the atmosphere are considered *ideal gases*, because they behave very similarly to the Ideal Gas Law. The gas law states that the temperature of air is proportional to its pressure. This relationship is illustrated by the graph in Figure E-1. The graph shows that when air *rises* in the atmosphere (i.e., goes from higher pressure to lower pressure), the temperature of the rising air decreases. For air that is not saturated with water vapor, the rate of temperature decrease with altitude is about 5.3°F per 1,000-foot elevation. It is important to note that air in the atmosphere is not continually rising or descending (i.e., not changing its pressure) and, therefore, the actual temperature of the atmosphere may not follow the graph in Figure E-1^{1/}. Also, the rate of temperature change with altitude is different for rising air that is saturated with water vapor than it is for rising dry (no water vapor) air. The temperature change with altitude of saturated air will be discussed later.

CONCEPT 3: PROPERTIES OF GASES AND MOISTURE IN THE ATMOSPHERE

Whether moisture in the atmosphere is in the invisible gas form of water vapor, in suspended liquid droplets or ice particles of a cloud, or as larger falling particles of precipitation, it plays the leading role in almost all weather phenomena. Moisture in the Earth's atmosphere commonly exists in three states: gas, liquid, and solid. In the gaseous state, known as water vapor, the water molecules (H₂O) diffuse perfectly and freely among the nitrogen, oxygen, and other gases in the atmosphere^{2/}. The liquid form of water is most commonly found in the atmosphere as tiny droplets that make up a large portion of

1/ The actual temperature in the atmosphere may increase with altitude (an inversion), have no change of temperature with altitude, decrease with altitude, or be some combination of increasing and decreasing.

2/ Although we cannot see water vapor, we can feel its effects. When water vapor is present in large proportions in the air in winter, heat is conducted from our bodies, and winds seem to chill us to the marrow. In summer a high content of water vapor in the air slows evaporation or perspiration from the skin, thus inhibiting body cooling, and we feel sticky, warm, and uncomfortable.

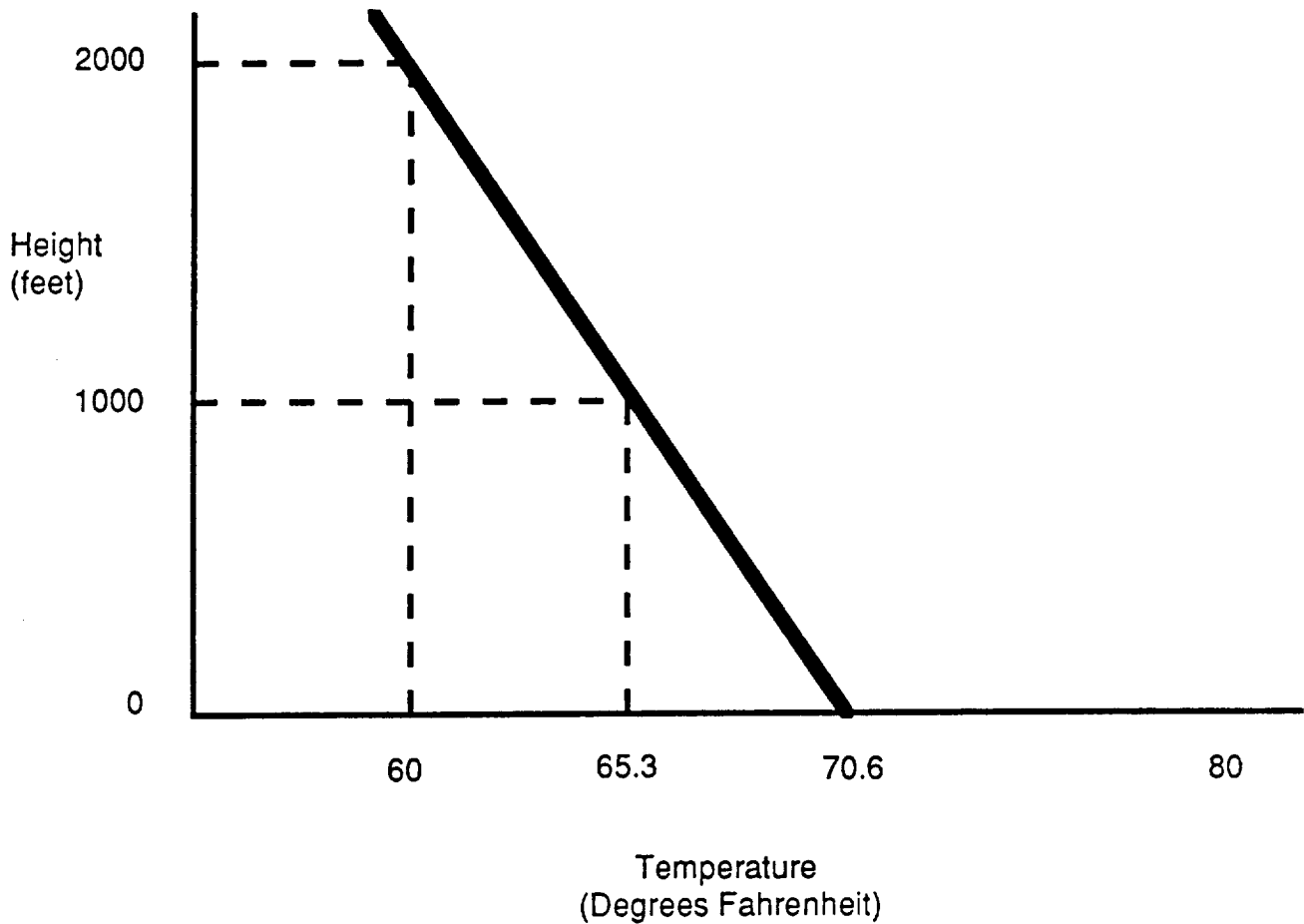


Figure E-1. The Ideal Gas Law states that the temperature of a gas is proportional to its pressure. The rate of pressure change with altitude in the Earth's atmosphere causes a rising volume of air to cool at a rate of 5.3°F every 1,000 feet of elevation. This graph shows the relationship between height and temperature for a particular rising volume of dry air. This air begins at a temperature of 70.6°F and cools to 65.3°F in the first 1,000 feet of rise. The air cools another 5.3°F in the next 1,000 feet to 60°F . This rate of cooling with height would continue were the air to keep rising.

clouds and fog. Liquid water also occurs as rain. Water in the solid state is most commonly found in the atmosphere as tiny hexagonal ice crystals high in the atmosphere. Clouds formed in the subfreezing regions of the atmosphere are often composed of ice crystals. Snow and hail are also solid forms of water in the atmosphere.

Moisture in the atmosphere may change back and forth between the gas, liquid, and solid states. When moisture changes from the gas state to the liquid state, it is called *condensation*. Moisture changing from liquid to gas is called *evaporation*. Liquid water may change to a solid in the process known simply as *freezing* and water vapor may change directly into crystalline ice by the process of *sublimation*. The reverse process, that of ice passing directly into water vapor, is also termed sublimation and is analogous to evaporation.

Whenever moisture changes from one state to another, heat energy is gained or lost. These processes are extremely important to understanding atmospheric phenomena. The process of evaporation consists of the flight of the most energetic, fastest moving molecules from the surface of the liquid into the air. When these molecules escape from the liquid, they take their extra energy with them leaving behind slower moving, less energetic liquid molecules. Since the energetic motions (speeds) of molecules in a liquid are related to the temperature of the liquid, the removal of energy (also referred to as *heat*) by the evaporating molecules lowers the temperature of the liquid. Consequently, evaporation is a cooling process ^{1/}. In the reverse process of condensation, the rapidly moving vapor molecules transfer their energy (heat) to the liquid when they collide with the liquid surface. The average energy of the liquid molecules increases, raising the temperature of the liquid. Condensation is therefore a warming process. ^{2/}

Similarly, heat is given up when liquid water freezes to a solid (ice). The *heat of fusion*, as this is called, is less than the heat transferred during condensation or evaporation. Sublimation, however, requires large quantities of heat to be transferred when water molecules change from the gas state directly to the solid state and vice versa. The heat transfer is larger than in the other processes because the change is from highly energetic and rapidly moving gas molecules to the very quiet repose of the molecules frozen stationary in an ice crystal. Sublimation includes the heat transfer of condensation and the heat of fusion combined. Sublimation of a solid to a gas requires heat energy to be added to the stationary molecules in the ice crystal to give them enough energy to move rapidly as a gas. Sublimation in both directions require the same heat transfer.

1/ When perspiration evaporates from the skin, it cools the skin by removing heat energy in the evaporating water molecules.

2/ Water vapor condensing on the outside of a cold can of soda pop will quickly warm the soda due to the heat transferred from the condensing molecules to the soft drink can.

The water vapor content of the air is generally referred to as the *humidity*. Since the absolute humidity of an air parcel^{1/} will change if condensation occurs and removes water vapor from the air parcel, meteorologists prefer to measure the moisture content of air using other terms such as *relative humidity*. Before defining relative humidity, consider what will happen to dry air in a sealed glass jar about half full of water left to stand without any change in the temperature of the surroundings. Evaporation will cause water molecules to leave the water surface and enter the air as vapor. At the same time, some of the vapor molecules will collide with the liquid surface and condense back into liquid. This means that the water molecules in the jar are continually going back and forth between the vapor state and the liquid state. At the beginning of the experiment, the rate of evaporation of water molecules will exceed the rate of condensation and a net amount of evaporation will occur. After a time, the number of water molecules leaving the water will be balanced by an equal number returning to the water surface from the vapor state. There is no further increase in the water vapor content of the air and the air is said to be *saturated*.

If the temperature in the jar were allowed to increase, however, additional evaporation would take place until saturation is achieved again. This is because more water vapor can exist in a volume of warm air than can exist in the same volume of cooler air.

The closed jar experiment demonstrates that at a particular temperature, there is a limit to how much water vapor can exist in a given volume. Furthermore, the maximum amount of water vapor that can be held in a given volume depends upon the temperature of the air in that space. A direct consequence of this relationship is that cooling a saturated volume of air will cause condensation, because only a smaller quantity of water vapor can exist in the volume at a lower temperature.

Relative humidity, therefore, is the ratio of the quantity of water vapor present in a volume to the maximum quantity possible in that volume. Put more simply, the relative humidity is the percentage of saturation. Relative humidity is given in percent, 0% being absolutely dry air, and 100% being completely saturated. In the closed jar experiment, the relative humidity begins low and eventually reaches 100%, or saturation. Quickly increasing the temperature in the jar will raise the maximum quantity of water vapor allowed in the volume. Raising the temperature will initially lower the relative humidity of the air until evaporation has added water vapor to the air and the relative humidity again reaches 100%. Cooling the air in the jar will cause condensation because the relative humidity cannot exceed 100%. That is, at a lower temperature, a smaller quantity of water vapor can exist in the volume and, therefore, some of the water vapor must be removed by condensation. Notice that when the air is cooled and water vapor condenses, the relative humidity does not change; it remains at 100%.

^{1/} An air parcel is a convenient method for describing a small volume of air which can move about in the atmosphere. An air parcel has no physical boundaries, but is usually defined as a volume of the atmosphere with horizontal dimensions of a few meters.

CONCEPT 4: THE RATE OF TEMPERATURE CHANGE WITH ELEVATION FOR SATURATED AIR

It was mentioned earlier that the rate of temperature decrease with altitude for a rising parcel of dry air was about 5.3°F per 1,000 feet, but that the rate of temperature change was different for a rising parcel of saturated air. For this discussion, consider a parcel of air at 100% relative humidity near the ground. We now know that when this parcel of saturated air moves upward in the atmosphere and the pressure drops, it causes the temperature to drop. In order to keep the relative humidity from exceeding 100%, however, condensation occurs and removes some of the water vapor from the air. Since condensation is a warming process, heat is returned to the parcel of air when water vapor condenses out of it. This means that the air parcel is partially rewarmed due to condensing water. Therefore, the rate of temperature decrease with altitude for saturated air (about 3.2°F per 1,000 feet) is less than the rate for dry air. In other words, if two parcels that are identical except that one parcel is saturated and the other is dry are lifted 1,000 feet up in the atmosphere^{1/}, the dry parcel will be 5.3°F cooler than when it started, but the saturated parcel will only be 3.2°F cooler.

It is important to remember that lifting a parcel of air up in the atmosphere is not the only mechanism for cooling the parcel. For a warm air parcel buoyantly rising through a cool atmosphere, the temperature of the parcel will decrease due to mixing with the cooler air around it as well as decreasing due to altitude. When these two cooling mechanisms are combined, the rate of temperature decrease with altitude may be substantially larger than either 5.3°F or 3.2°F per 1,000 feet.

CONCEPT 5: CLOUD FORMATION

Clouds are collections of tiny water droplets or ice crystals suspended in the air and are formed by many different sets of atmospheric conditions. Their shape, size, and altitude are often indicative of the atmospheric conditions that produced them. Clouds are formed when water vapor condenses on tiny particles^{2/} forming tiny spheres of water or ice (usually about 10 to 50 μm in diameter). These cloud droplets and ice particles are so small that they remain suspended in the atmosphere.

The following example illustrates the cloud formation process. An air parcel at an elevation of 100 feet has a relative humidity of 75%. This air parcel is lifted in an updraft, causing the temperature to drop and the relative humidity to increase. When the air parcel gets to an altitude of 1,500 feet, the relative humidity reaches 100%. As the air parcel

^{1/} Air parcels may be lifted in updrafts, or when air must flow over an obstruction such as a mountain.

^{2/} The tiny particles are called cloud condensation nuclei (CCN) and are everywhere in the atmosphere. CCN are made of specks of dust, sea salt, and other chemical compounds.

continues to rise in the updraft, the temperature continues to decrease, but the air parcel cannot hold all of the water vapor that it could originally. Therefore, some of the water vapor condenses onto the tiny particles in the air and cloud droplets are formed. The collection of tiny droplets constitutes a cloud. If the temperature of the cloud were to drop much below freezing (-33°F), the cloud droplets would freeze into ice crystals^{1/}. In a subfreezing cloud, the water vapor may also sublime onto particles and form ice crystals.

CONCEPT 6: RAIN FORMATION

The formation of a cloud by condensation and sublimation is the first step in producing precipitation. However, merely forming a cloud does not water the earth, for the terminal velocity of a cloud droplet with a radius of $10\text{ }\mu\text{m}$ is about one half an inch per second; at this rate, it would take about 80 hours for the water to reach the ground from the average cloud level, about 1.5 to 2 miles high. Furthermore, raindrops usually must fall through layers of unsaturated air before reaching the ground. A $10\text{ }\mu\text{m}$ cloud droplet would survive through only a few feet in air with a relative humidity of 90% before evaporating. Therefore, the formation of rain involves processes which dramatically increase the size of the drops.

Raindrops are formed in clouds by the frequent collisions of cloud droplets with one another and by the rapid growth of ice crystals. In very warm climates such as the tropics, entire clouds will have temperatures above freezing and no ice crystals will be present. In these *warm clouds*, raindrops are formed by the collisions of millions of cloud droplets to form a single raindrop^{2/}. Although warm clouds can produce copious quantities of rain, the process of raindrop formation by droplet collision is fairly slow. Estimates of the time required for a drop to grow to about 0.05 inches in diameter (a small raindrop) by collision range from about 45 to 60 minutes for a typical cumulus cloud. This means that a cloud must have a continual supply of saturated air and a constant updraft for at least 45 minutes before the first raindrop can fall to the ground.

Raindrops are also formed when falling ice particles melt before they reach the ground. This theory was developed in the early part of this century and is now believed to be the main mechanism for rain formation in the mid-latitudes of the globe. An earlier discussion mentioned that ice crystals may grow by sublimation when the cloud temperature is below freezing (*cold clouds*). The rate of sublimation of water vapor onto ice particles in clouds, however, is much greater than the rate of condensation. Therefore, an ice crystal may grow into a small snowflake while the liquid cloud droplets remain very tiny. The small snowflake may then aggregate with other ice crystals to form a precipitation-sized snow flake in about 30 to 40 minutes. As in the case of warm clouds,

^{1/} Cloud droplets will remain as liquid droplets even under very cold conditions (down to about -33°F) is called a supercooled droplet. Many clouds consist entirely of supercooled droplets.

^{2/} The average rain drop contains roughly one million times the quantity of water found in a single cloud droplet.

cold clouds require a continuous supply of saturated air and a constant updraft for at least 30 minutes before rain will fall. When the supply of saturated air ceases, raindrop formation will stop and no precipitation will fall. Raining clouds may be thought of as rain machines, requiring a conveyor belt carrying water vapor (saturated air in an updraft) to feed them with the water to create the rain. If the conveyor belt stops, the cloud machine may remain intact, but the production of rain will stop.

QUESTIONS CONCERNING METEOROLOGICAL EFFECTS ON THE ASRM TEST PLUME

- 1) What effect will the humid climate in southern Mississippi have on the buoyant rise and dispersion of the exhaust plume?

The ASRM exhaust plume rises from the ground to high elevations due to thermal buoyancy. The hot exhaust plume is less dense than the ambient air and, therefore rises (Concept 1). The combustion of the solid fuel will produce an exhaust plume with a high percentage of water vapor by weight, about 6%^{1/}, but will initially have a low relative humidity due to its high temperature. The exhaust plume will rapidly cool as it rises in elevation (Concept 2) and as it mixes with the much cooler ambient air. Since the exhaust plume initially contains a large quantity of water vapor and since the ambient air in southern Mississippi has a high humidity, the plume will soon reach the point where it becomes saturated (Concept 3). At this point the saturated plume will still be very hot and will thus continue to rise. After the plume becomes saturated, water vapor will begin condensing (Concept 4) which will add additional heat to the plume. The rate that the plume cools with elevation after it becomes saturated will be slower than before it became saturated (Concept 5). When a rising plume cools to the temperature and density of the surrounding air, it will stabilize and stop rising. A plume which is initially warmer than its surroundings, will rise until its density has decreased to that of the surrounding air. Since the saturated plume will remain warmer than the ambient air for a longer time than if the plume were not saturated, it will also remain less dense than the ambient air for a longer time (Concepts 1 and 4). Therefore, a saturated plume will rise to a higher elevation than an unsaturated plume.

For a saturated plume, the sooner it reaches saturation (i.e., the lower the elevation), then the higher the plume will rise. That is, the sooner the plume reaches saturation, then the sooner it will begin to cool with elevation at the saturated rate of 3.2°F per 1,000-feet (cooling rate for dry air is 5.3°F per 1,000-feet). The high humidity of the ambient air around Stennis Space Center (SSC) will allow the plume to become saturated earlier than if the air were dry (low humidity). This is because when the hot plume mixes with humid air, the resulting mixture will also have a high water vapor content, whereas mixing the plume with dryer air would create a mixture with a lower water vapor content. The

^{1/} Humid air in the tropics typically contains up to 4% water vapor by weight.

humid climate at SSC, therefore, favors high plume rises.^{1/} Since the plume dispersion is greater for higher plume rises, the humid climate at SSC aids in the dispersion.

The plume rise from Shuttle launches at KSC is fundamentally different than at SSC for several reasons. During a Shuttle launch at KSC, the launch pad is deluged with millions of gallons of water just prior to launch. Additionally, water is sprayed onto the pad and launch facility during the launch. The hot exhaust from the SRMs evaporates the pool of water and the liquid droplets being sprayed onto the launch pad. Since evaporation is a cooling process (Concept 3), the evaporating water dramatically cools the exhaust and reduces its ability to rise.

Another major difference between the Shuttle exhaust plume and an ASRM exhaust plume at SSC is that the majority of the Shuttle exhaust is emitted along the Shuttle flight path in a long column. Since the Shuttle plume is very spread out, it mixes quickly with the surrounding air and cools. Plume rise is not a major factor in the dispersion of a Shuttle exhaust plume.

The plume rise process at the Utah test site is similar to the process at SSC in most respects. The major difference between the Utah test site and SSC is the higher humidity at SSC than at the Utah site. As demonstrated above, higher humidities allow the plume to reach saturation at a lower level and thus increases the plume rise.

2) Will the rising plume create its own cumulus cloud and produce acid rain?

The rising exhaust plume will reach saturation on its way up and water vapor will condense into tiny droplets. The plume will then consist of cloud droplets, exhaust gases, and aluminum oxide particles. As the plume continues its ascent, it may take on the appearance of a cumulus cloud. As the plume reaches its final elevation, the temperature in the plume may be below freezing^{2/} and some of the water vapor may sublime into ice crystals. When the plume has risen to its final elevation a couple of minutes after firing, the temperature will cease to drop and the condensation and sublimation processes will stop. Observations of SRM exhaust plumes in Utah show that the cloud formation processes stops after about five minutes.

Conditions could exist in the atmosphere around Mississippi which would allow the plume to continue rising for several thousand feet more than has been predicted by computer models. These are the same conditions which give rise to the naturally occurring tall cumulus clouds. Droplet and ice crystal growth would then be able to continue for several more minutes. However, unless the atmospheric conditions already existed that would create a raining cumulus cloud, the exhaust plume-cloud would have

^{1/} Exhaust plumes from SRM tests in Utah typically rise to elevations of 10,000 feet or more. However, if the humidity of the air near the ground at the Utah test site were as high as the air at Stennis, the plumes could rise to even higher elevations.

^{2/} Upper air temperature data from Slidell, MS indicate that freezing temperatures may occur at about 10,000 feet year round.

no continued source of saturated air and no continuous updraft after it reached its final elevation. That is, if moisture-laden air is not already rising and forming raining cumulus clouds, then after the short puff of hot moist air from an ASRM test rises off the ground, cooler, non-buoyant air will move in to fill the void but will not rise. The ice crystals and cloud droplets could not grow into precipitation-sized particles without a continued source of rising saturated air (Concept 6). Since the time required for a droplet or an ice crystal to grow into a precipitation-sized particle is so much longer than the length of the test firing and the length of time the plume is rising, there would not be enough moisture supplied or a long enough period for precipitation-sized drops or ice crystals to form. Even in the humid environment of southern Mississippi, the exhaust plume alone could not produce rain.

If the meteorological conditions already exist at the time of firing which would tend to produce a *raining* cloud, then formation of such a cloud could begin spontaneously with a buoyantly rising mass of air. However, if raining cumulus clouds are forming or have the potential to form naturally, then ASRM testing will not proceed. These conditions are readily identified by meteorologists monitoring the weather. ASRM testing will only proceed when the atmosphere cannot spontaneously produce raining cumulus clouds. Under such test conditions, the exhaust plume would be both too small and last for too short of a time to start the formation of a raining cumulus cloud. Therefore, the HCl in the plume would not be immediately rained to the ground.

APPENDIX F

Potential Role of Aluminum in Alzheimer's Disease

APPENDIX F

POTENTIAL ROLE OF ALUMINUM IN ALZHEIMER'S DISEASE

INTRODUCTION

Most scientists agree that there are neuropathological similarities between aluminum neurotoxicity and Alzheimer's disease (AD). However, the contribution of environmental exposure to aluminum in the development of Alzheimer's disease is not well understood (Henderson and Finch 1989). This appendix summarizes the evidence and opinions contained in the scientific literature regarding the role of aluminum in the etiology (i.e., cause or origin) of AD. This discussion is not intended to be a detailed presentation of the entire database; rather, its purpose is to present a concise and factual interpretation of the most accepted theories and observations regarding AD development.

A common disease of unknown origin, AD affects approximately 2 million Americans with its incidence and prevalence increasing with age (Mozar et al. 1987). The prevalence of severe dementia attributed to AD in persons over 65 years is estimated to be 1 to 6 percent (Henderson and Finch 1989). Progressive symptoms of AD include the loss of cognitive functions, learning ability, and memory; disorientation; an altered ability to communicate; personality changes; and eventually death (Thienhaus et al. 1985). The illness is irreversible and generally lasts about 7 years. The most common pathological characteristic of AD is the development of neurofibrillary tangles and neuritic plaques in certain regions of the brain associated with cognitive functions (i.e., hippocampus and neocortex) (Henderson and Finch 1989). These tangles appear as large clusters of unbranched fibrous structures that are twisted into a helix. These neurofibrillary tangles and neuritic plaques, although conspicuous in AD patients, are also observed during the normal human aging process and in a number of dementing disorders (Henderson and Finch 1989).

RESEARCH OBSERVATIONS

The theory that aluminum has an etiological or pathogenic role in AD was originally based on four observations: 1) certain epidemiological studies correlated the rates of AD with aluminum concentrations in drinking water and soils; 2) native Chamorro populations on Guam develop neurodegenerative diseases (with similar features as seen in AD) and accumulate large amounts of aluminum in their neurofibrillary tangle-bearing neurons; 3) aluminum was found in elevated concentrations in the neurofibrillary tangles of AD patients; and 4) injection of high concentrations of aluminum salts into laboratory animals produced neurofibrillary tangle-like structures, similar to those observed in AD patients. These observations and studies related to alternative theories are discussed below.

EPIDEMIOLOGICAL STUDIES

Several epidemiological studies (the science concerned with investigations into causes, frequency, and distributions of disease in human populations) reported a correlation between elevated levels of aluminum in drinking water and an increased incidence of AD, relative to control populations. These control populations were selected from areas where aluminum in drinking water was lower (Martyn et al. 1989; Flaten, T.P. 1986). In one of the more controversial studies, Martyn et al. (1989) reported that the risk of Alzheimer's disease was 1.5 times higher in districts where the average aluminum concentration exceeded 0.11 mg/l than in districts where the drinking water concentrations were less than 0.01 mg/l. Although this study did find a positive correlation, many research scientists have reacted critically to the study, citing serious methodological flaws in the selection of cases, and in the statistical analyses, uncertainty in actual aluminum water concentrations, failure to demonstrate a dose-response relationship, and the drawing of premature conclusions given the quality of their data (Ebrahim 1989; Schuph et al. 1989; Klepak 1989). Indeed, the daily doses of aluminum indicated by Martyn et al. (1989) are relatively insignificant considering that the normal daily intakes of aluminum from the diet and drinking water average between 5 mg and 50 mg (Martyn et al. 1989; Taylor 1984). Furthermore, cases of dementia were selected from CT scan records and are only suggestive of Alzheimer's disease. Neuropathological examination is commonly regarded as a requirement for a definitive diagnosis of AD (Martyn et al. 1989). As Martyn et al. (1989) stated, studies have shown that diagnosis of AD based solely on clinical evaluation is about 80 percent accurate when compared to neuropathological examination. However, if 20 percent or more of the AD cases are misdiagnosed as a result of clinical evaluation, this would have a dramatic impact on the results and conclusions of this study.

Guam Studies

Among the natives of the island of Guam, large numbers of individuals suffer from amyotrophic lateral sclerosis (ALS) and/or Parkinson-dementia (PD). More recently, cases with pure dementia and/or progressive supranuclear palsy (a Parkinson's disease-like condition with paralysis of downward and upward gaze) have also been observed with high prevalence among Guamanians. Importantly, the brains of affected natives show extensive involvement with most of the neuropathologic lesions encountered among patients with AD. Over 35 years of detailed epidemiologic studies on Guam have consistently shown that whatever causes this unique epidemic of neurodegenerative disease is related to unique local environmental factors, with little underlying influence of genetic factors in Guamanians (Garruto and Yase 1986). Of importance to this discussion is the observation that the brains of affected Guam natives accumulate 300 times the aluminum concentration as do adjacent nontangled neurons or of those of normal subjects (Perl et al. 1982; 1986).

It is still unclear how aluminum accumulates within the brains of affected Guam natives, nor is it known if aluminum represents a cause or effect of the neurologic disorders seen on the island. In this regard, a potentially important observation has just been reported by

Perl and coworkers (Perl et al. 1990; Steele et al. 1990). They have reported that Guamanian patients who are early in the course of Parkinson-dementia show a profound deficit in olfactory function. They also note that at autopsy Parkinson-dementia patients show particularly severe damage to the olfactory bulbs and associated structures. They have suggested that the cause of the Guam Parkinson-dementia epidemic may represent an airborne factor rather than one which enters the brain via the blood stream through a blood-brain barrier. This study suggests that airborne environmental factors may play a more important role regarding the subsequent development of neurodegenerative diseases than we have previously recognized.

Currently, an interesting hypothesis about the etiology of ALS and PD in Guam concerns exposure to the highly toxic seeds of the false sago palm (*Cycas circinalis* L.), which was used in food and traditional medicine until shortly after World War II (Spencer et al. 1987). *Cycas* seeds contain a neurotoxic amino acid (beta-N-methylamino-L-alanine or BMAA), which has been demonstrated to induce motor neuron and behavioral dysfunctions and neuropathological changes (Spencer et al. 1987). While this hypothesis has been challenged (Garruto et al. 1989), it is undergoing intensive evaluation and offers a good explanation for such factors as latency period, recent dietary changes, declining incidence of disease, and geographical variations in disease rates. However, since Spencer's original publication, many subsequent studies have been unable to reproduce his results. It is therefore unclear whether BMAA represents a plausible explanation or is merely another of the many theories of the development of AD.

Further study of ALS and PD in Guam natives may more clearly elucidate the role of environmental and genetic factors in neurofibrillary tangle formation, such as that observed in Alzheimer's disease (Perl and Good 1987). Whatever combination(s) of genetic and environmental factors that may be responsible for neurological disorders on Guam, it requires a long time (around 20 years) for immigrants to develop such disorders. Genetics may play a role in AD and PD, but whether it is a critical role and whether it has anything to do with aluminum absorption remains unclear.

Elevated Aluminum Levels in AD Patients

Elevated aluminum concentrations have been observed within neurofibrillary tangle-bearing neurons of deceased AD patients, while adjacent normal-appearing neurons, as well as those from controls, were virtually free of aluminum (Perl and Brody 1980; Perl and Pendelbury 1986). It is unclear whether aluminum accumulation occurs secondary to neuronal injury or whether the neurotoxic effects of these minerals contribute to AD pathology (Henderson and Finch 1989; Crapper McLachlan et al. 1985). Several theories exist to explain the preferential buildup of aluminum in neurofibrillary tangles, such as transferring-mediated transport (movement via an iron-binding protein) and buildup of amyloid proteins (Edwardson and Candy 1989). Nevertheless, this issue remains unresolved. It is important to note that AD is strongly age-related and that the native Guam population is especially sensitive to PD. Furthermore, aluminum is widely distributed in the environment and ordinarily it does not pass either the intestinal or

blood-brain barrier. There is no known biological function of aluminum. It is entirely possible that the presence of aluminum in the tangled neurons in patients with AD and PD may follow pathological degeneration of the neurons and, hence, represents an effect rather than a cause of these disorders. It appears that as the body ages, levels of aluminum in the brain slowly increase (Ganrot 1986), although in AD, the aluminum accumulation is restricted to neurofibrillary tangles while adjacent neurons have normal aluminum levels. This slow accumulation combined with an unknown predisposing factor has been suggested as an explanation of the cause of AD (Ganrot 1986). This hypothesis has yet to be confirmed.

Aluminum-Induced Neurofibrillary Tangles

Aluminum injected intracranially (directly into the brain) into experimental animals induces development of neurofibrillary tangles and cognitive dysfunctions that are similar to those seen in patients with AD (Edwardson and Candy 1989; Perl and Good 1987). Cognitive dysfunctions are also observed. Furthermore, dialysis encephalopathy (unique degeneration of the brain seen in dialysis patients) has been observed in some long-term dialysis patients (patients with kidney failure) treated with aluminum-containing phosphate binding gels (Taylor 1984).

Unlike AD, dialysis encephalopathy can be reversed by using chelating agents which bind with metals like aluminum to enhance their removal from the body. Additionally, twitching and seizures are common in dialysis encephalopathy, although not observed in AD. AD has generally not been observed in patients with renal failure or end-stage renal disease, despite unusually high brain levels of aluminum (Arieff et al. 1979; Burks et al. 1976). It appears that overall aluminum levels are higher within astrocytes and endothelial cells in the cerebral cortex and aluminum is not being accumulated within the neurons (Good and Perl 1988). Also, it is not known how long it takes to develop a neurofibrillary tangle, although it is thought to take years.

Alternative Theories of Alzheimer's Disease Etiology

The aluminum theory has received much attention, but it is only one of many plausible theories of etiological causes of AD. Hypotheses that a genetic abnormality may be responsible for the development of AD are supported by findings of an increased prevalence of dementia among siblings of AD patients (Heyman et al. 1983), and neuropathological similarities between AD and trisomy 21, or Down's syndrome (Henderson and Finch 1989). Other studies of Alzheimer's disease report that only one member of identical twins was affected with the disease, thus contradicting theories of a simple genetic familial link. Also, investigations aimed at identifying the gene responsible for AD have been negative (Henderson and Finch 1989).

Scientists have hypothesized that viruses may play a role in AD. The viral theory is particularly interesting because many viruses, such as herpes simplex virus, are known to invade the central nervous system (Henderson and Finch 1989). Evidence of a causal role

of viruses is at best circumstantial and mostly negative. In fact, many leading researchers have dismissed the viral theory.

As an additional theory, head injury has been associated with dementia and AD in latter years of life, although this observation is somewhat controversial. Several small case-control epidemiological studies have linked the development of AD to previous head injuries in boxers (Henderson and Finch 1989). In contrast, one larger, well-designed prospective study did not show a significant correlation.

SUMMARY OF THE POTENTIAL ROLE OF ALUMINUM IN ALZHEIMER'S DISEASE

The cause or causes of Alzheimer's disease remains unknown. There is a lack of compelling evidence to support the hypothesis of a direct causal role of aluminum or any other genetic or environmental factors in the development of Alzheimer's disease. Like most diseases, the cause or causes of AD may someday be determined to be a combination or interaction of genetics and as-yet unidentified environmental factors.

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APPENDIX G

Medical Expert Consultation and Review

APPENDIX G

MEDICAL EXPERT CONSULTATION AND REVIEW

The text submitted to the medical experts for review was subsequently revised to reflect their suggestions. This revised text appears in the document (see Section 5.0). Appendix B, Potential Role of Aluminum in Alzheimer's Disease, referred to in the following letters, is now Appendix F in this document.



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MAY 23 1990

EBASCO ENVIRONMENTAL
BELLEVUE

May 22, 1990

William E. Maier
Toxicologist
Ebasco Environmental
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Dear Mr. Maier:

I have now reviewed the revised version of Section 4.0 (Human Health Effects) of the Supplemental Environmental Impact Statement of emissions from testing of the NASA Advanced Solid Rocket Motor (ASRM). As requested, I offer the following comments and suggestions:

The main body of the document (Sections 1.0-5.0) deals with many areas outside my expertise but generally appears to reasonably summarize the situation. I did not detect any serious problems with what is stated in this portion and cannot offer any further suggestions or revisions.

My comments are directed primarily at Appendix B (The Potential Role of Aluminum in Alzheimer's Disease). Appendix B opens by stating that the contribution of aluminum in the development of Alzheimer's disease is not well understood. I agree with this assessment and have stated similar views in my own publications. For this statement you cite Henderson and Finch, a reasonable review article covering a wide range of topics. It was written by knowledgeable authors who are engaged in Alzheimer's disease-related work. However, a second citation is provided which is from a letter to the editor to the Lancet written by Professor Trevor Hughes of Oxford. You should be aware that such letters to the editor are not subjected to peer review and can be extremely variable in their accuracy and the nature of the views expressed. While Professor Hughes holds a senior position in neuropathology in Great Britain, let me point out that he has not engaged in research on aluminum or Alzheimer's disease, does not regularly publish in this field, and is widely acknowledged to be a paid consultant to the British aluminum industry. In the last few years his professional reputation has been somewhat tarnished as a result of his vociferous and vehement denial, before the

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lay press and governmental agencies, of any role for aluminum in Alzheimer's disease. For the reasons stated above, I suggest that you not use this Hughes reference.

On page B-2, line 1 the use of the word "pathological" is, I believe, incorrect and "pathogenetic" should be substituted. More importantly, of the three observations listed, mention is made of an association of rates of AD with aluminum concentrations in the soil. I am not aware that anyone has ever made claims about an association of Alzheimer's disease and soil aluminum content. I am not aware that this has ever been studied. If you are referring to data from Guam soil then that is a different matter. I personally believe that the data from Guam warrent inclusion as a 4th observation on your list of supporting findings, namely, that the native Chamorro population on Guam develop neurodegenerative diseases with many features of AD and also accumulate large amounts of aluminum in their neurofibrillary tangle-bearing neurons.

On page B-4 you refer to the cycad hypothesis as a "leading" hypothesis. Hypotheses "lead" only because they generate increasing amounts of supporting scientific data, not because they attract increasing attention in the press. Since the publication of Spencer's original article in Science (Science 237:517, 1987) claiming that BMAA causes lower motor neuron and behavioral disfunction in monkeys, virtually all subsequent published studies have been of a negative nature. You cite Garruto's challenge to the hypothesis but I believe you should also be aware of and cite the recent report of Perry and coworkers (J. Neurol. Sci. 94:173-180, 1989). They fed mice large amounts of BMAA (15.5 gm/kg, a huge dose) over an 11 week period and did not encounter any behavioral abnormalities or evidence of neuropathologic or neurochemical changes in the group of treated animals. I am personally aware of one additional laboratory with similar negative (though unpublished) results. It is noteworthy that even Spencer no longer claims that BMAA is the neurotoxic factor of importance in cycad (see Science 248:144, 1990). Finally, Duncan, et al. (Neurology 40:767-772, 1990) found that most of the BMAA was removed in the processing of cycad and that flour samples prepared on Guam actually contained extremely low levels of the proposed toxin. As far as I am concerned, cycad-related neurotoxins merely represents another hypothesis. I believe that calling it a "leading" hypothesis, overstates the situation. If you wish to give a balanced view of this subject, the above must be kept in mind.

In the last paragraph of page B-4 mention is made that elevated concentrations of silicon were observed in neurofibrillary tangle-bearing neurons of AD victims and two of our papers are cited. The data referred to relates to our original study published in Science (Perl and Brody, 1970). In this article we did not claim that silicon was elevated in tangle-bearing neurons. For a variety of technical reasons, silicon is very difficult to detect with certainty using X-ray spectrometry and we never felt that the data related to silicon were very compelling. Furthermore, subsequent laser microprobe mass analysis studies (a much more sensitive and definitive method for detecting silicon in tissues) has

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repeatedly failed to show elevated silicon concentrations in the neurofibrillary tangle-bearing neurons of AD. I believe that in this context any reference to silicon accumulation should be deleted.

I reject the subsequent argument on the top of page B-5 that since aluminum accumulates in some organs with increasing age, the increases seen in AD may reflect some non-specific aging change. First, the aluminum concentrations seen in the tangle-bearing neurons of AD are 15 to 100 times higher than those of age-matched controls or even the adjacent non-involved cells of AD cases. Furthermore, a number of other trace elements are increased in concentration in the organs of elderly individuals and yet these elements are not encountered in the tangle-bearing neurons of AD. Why should such a non-specific mechanism be applicable for just one element when it comes to the damaging effects of Alzheimer's disease? Because science cannot currently explain the specificity of an observation does not necessarily mean that it is therefore non-specific in nature.

In the discussion of dialysis dementia mention is made that when neurofibrillary tangles are present in this disease they are different from those seen in AD. Reference is given to Monteagudo, et al. I am not familiar with this paper, nor do I recognize any of authors' names. Unless this observation is based on a well documented scientific study (which I doubt) then I think this material should not be included in the discussion. In the last sentence of this paragraph (top of page B-6) I think you should say that the patients may die before The concept invoked regarding the time element needed to develop a neurofibrillary tangle is purely conjecture on my part and is not based on any firm evidence.

Finally, the discussion on alternative etiologic hypotheses for Alzheimer's disease (particularly the last paragraph, page B-7) seems to miss the point. No one knows what causes Alzheimer's disease but it is unlikely that only one mechanism is involved exclusively. I have argued that similar to most of the other chronic diseases of the elderly, Alzheimer's disease very likely represents an interaction of both genetic factors and a variety of environmental factors. Atherosclerosis leading to myocardial infarction may be regarded as a model for this concept where the underlying factors are better understood. For instance, familial hypercholesterolemia represents a strong genetic factor which may lead to familial clusters of premature heart attacks yet, within these families, the dangers of certain environmental factors, such as cigarette smoking or dietary excess, may serve to further exacerbate the situation. I have enclosed a copy of a short commentary that I recently wrote which discusses this concept further.

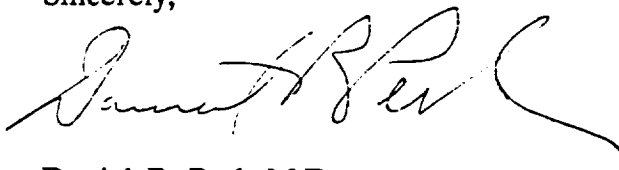
The final discussion related to evidence for underlying genetic factors appears to assume that any positive evidence for such genetic factors serves to lessen the possibility that environmental factors may play a role in the production of the disease. The

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concept that one hypothesis is mutually exclusive of the others represents a poor approach to a disease like Alzheimer's disease. As you say in the final sentence, it may be (in my belief, it is highly likely) that Alzheimer's disease is caused by an interaction of both genetic and environmental factors. If that concept is accepted then we must begin to look for what possible factors may be implicated. As we agree, no specific environmental have yet been clearly linked to the disease. Nevertheless, some factors have attracted attention and have associated data which would tend to support their possible contribution to the process. Aluminum, among others, is in that category. Head trauma would be another. Beyond that, we know very little. However I think that it is naive to consider the cause of AD to related to genetic factors in the absence of any supervening environmental ones. There are some neurogeneticists who would argue this point, but many concede that there are very few purely genetic disorders, particularly among the elderly.

I do believe that the comments of the outside consultants have made for a better report and I hope that the above commentary has been helpful. If I can be of further assistance to you, please let me know.

Sincerely,

A handwritten signature in cursive script, appearing to read "Daniel P. Perl", followed by a long horizontal flourish.

Daniel P. Perl, M.D.
Professor of Pathology
and Psychiatry
Director, Neuropathology
Division

DPP/ems
Enclosure

REVIEW AND CRITIQUE OF NASA SUPPLEMENT
TO THE FINAL ENVIRONMENTAL IMPACT STATEMENT
FOR THE SPACE SHUTTLE ADVANCED SOLID ROCKET MOTOR (ASRM) PROGRAM

Leonard T. Kurland, M.D., Dr.P.H.
Professor of Epidemiology, Mayo Clinic, Rochester, MN, 55905

If the conclusions of the F.E.I.S., that human health effects of the known pollutants released during static testing (primarily HCl and aluminum oxide) are correct and that the ambient air concentrations outside the SSC buffer zone are below the recommended air quality standards or guidelines, there would be little if any risk to humans, animals and plants from these tests. The infrequency and brevity of such testing and the expectation of the design of the rocket test stand (to assure plume that will provide adequate dispersion and an enormous dilution factor) as well as the choice of the most desirable and available atmospheric conditions of temperature, humidity, wind speed and wind direction, would assure safe dilution and dissemination of the known pollutants.

HCl alone, in the concentrations expected, does not provide any risk that this reviewer regards as significant. The risks could be of greater concern if one were dealing with H_2SO_4 , since these might have a greater biological effect. But H_2SO_4 is not the problem.

The primary concerns relate to the aluminum oxide-HCl mixture, the question of the chemical composition of these products, and the effects on animals of aluminum compounds, particularly acid-coated aluminum oxide. Aluminum oxide in pure form in the expected concentrations is regarded as quite safe; if aluminum chloride is produced, there is greater uncertainty, since that compound in high concentrations is reported as capable of entering the central nervous system through the fibers of the olfactory nerve. However, studies of aluminum oxide in upper level airborne samples of the shuttle's plume indicate no aluminum chloride. There is no comment regarding lower altitude sampling.

At the present time there is considerable research underway to determine whether an aluminum compound is related to the cause of Alzheimer's disease (AD), the parkinsonism-dementia complex of Guam (PDC), and other neurodegenerative diseases. We must first acknowledge that aluminum, although widely present in the environment, does not ordinarily pass the intestinal barrier nor the blood-brain barrier. Furthermore, its presence in the two conditions mentioned (AD and PDC) may follow degeneration of the neurons due to other causes and, therefore, represent an effect of the degeneration rather than a cause of these disorders.

Thus, an effort to determine whether aluminum chloride is produced and in what concentrations, combinations, and forms (e.g., aerosols) it may be present at different locations, seems essential in order to provide the needed reassurance as to public safety.

With regard to the question of the causes of AD and PDC, there is brief reference to genetics, infections, trauma, and toxins, all of which are under intensive study. Genetic factors probably play a role in some cases of AD, also in Parkinson's disease and amyotrophic lateral sclerosis (ALS) -- perhaps on the order of 10% to 20% or even more. Features of all three of these conditions have been found in the PDC of Guam, the disease which shows an even greater concentration of aluminum than do cases of AD. The exact form and the mechanism whereby the dying or dead neurons accumulate aluminum is under study. Aluminum speciation and the concentration of other elements, such as calcium and magnesium in the water and soil, may influence the absorption and the distribution of aluminum to the central nervous system. Low calcium and magnesium reported on Guam have been found in only a single limited water supply. The soil of many other locations (e.g., Jamaica) is probably higher, although solubilities may differ. In contrast to the statement from F.E.I.S., calcium and magnesium levels in the soil, water and food intake of the Guamanian population are quite adequate. Although aluminum is excluded from entering the blood and

brain normally, the role of reduced pH and the variability in speciation may influence the absorption of aluminum and possibly affect its passage through the tissues. This is an area that requires further study.

So genetics may indeed play a role in AD and PDC, but whether it is a critical role and whether it has anything to do with aluminum absorption remains uncertain. We cannot disregard the knowledge that AD is strongly age-related and that the native population of Guam is especially predisposed to PDC, but again the pathophysiologic mechanism is unknown.

There is little evidence that AD or PDC are disorders related to viral or other infections or are post-infectious. The role of trauma in AD is controversial, but the only large prospective study (recently completed) has not shown a significant correlation and that study is regarded by this reviewer as superior in design to the several retrospective case-control studies (subject to serious recall bias) that have suggested that prior head trauma was an etiologic (causative) factor. The role in PDC of neurotoxic amino acids from the cycad seed and the role of receptor sites for such amino acids in AD is being explored intensively. Although other toxins may contribute to the etiology of AD, for the present time we are obliged to consider aluminum as a candidate toxin and try to evaluate its role. To do so, I shall comment on the points raised in the Supplement as these relate to aluminum and its respective role in the aforementioned neurodegenerative diseases.

In the article by Henderson and Fitch, the conclusion is reached that the role of aluminum has not been resolved. About two-thirds of all dementia diagnosed in Rochester, Minnesota (and presumably in the U.S.), is regarded as due to AD, which is characterized by neurofibrillary tangles and neuritic plaques (which incidentally do not contain "inflamed or damaged nerves,") since an inflammatory process is not associated with this condition.

The work of Martyn et al. on aluminum in various county water supplies in England and Wales is compared to the use of CT scans and provides no evidence of an association with prevalence rates. This indirect approach cannot be regarded as an accurate or complete assessment of the issue. This reviewer would agree with the criticism of this study as noted by Hughes (1989), Ebrahim (1989), and others. Furthermore, the normal daily intake of aluminum overrides the slight difference noted in the water supplies studied by Martyn et al.

With regard to antacid and antipersperant use, there is no study that this reviewer is aware of that convincingly shows an association of aluminum use and dementia.

The incidence of dialysis encephalopathy appears to be related to pH and the concentration of aluminum ions in the dialysate. Although neurons may not be affected in the acute stages of this illness, it has been shown that aluminum may be present in the glial or supportive elements of the brain.

Aluminum accumulates in the damaged areas of the brain in AD and PDC, but whether aluminum is the primary etiologic entity or is merely associated with something present previously that is the cause of the neuronal degeneration remains to be clarified. The general tone of the Supplement is to dismiss aluminum as causative in AD. The pathogenetic mechanism of aluminum is uncertain and will require further elaboration before that position is justified; of course, the same can be said regarding the need for further studies to prove that aluminum plays a primary etiologic role in AD.

However, Perl and Good have shown that very high concentrations of aluminum chloride applied to nasal epithelium of rabbits resulted in the entry of aluminum compounds through the olfactory nerve and that adjacent areas of the brain which are analagous to those thought to be involved in early human AD also contained increased aluminum. Guam PDC subjects show loss of neurons in the olfactory bulb and the

loss of odor identification capabilities. We are exploring the possibility that suspected toxins may enter through the olfactory rather than the gastrointestinal system.

This Supplement appropriately indicates the lack of clear correlation data regarding dose, speciation, or even of a mode of exposure to aluminum in diseases where aluminum has been found. However, the effect of HCl on the aluminum compounds in the plume should be reported. The concentrations described for HCl and aluminum oxide (Table 4-1) are so low that these would appear to be of no significant risk to any population beyond the buffer zone.

Whether the brief periodic emissions of large quantities of aerosolized aluminum and HCl serve as a significant health risk is a difficult point for me to respond to since the criteria for a specific recommendation have not come to my attention. It would be helpful if populations known to have been exposed at the approximate levels anticipated here could be followed and compared to similar populations not known to have had such exposure. At the time there appears to have been no untoward effect of the numerous rocket uses in the space shuttle program. Furthermore, at the concentrations described and for the duration expected periodically (totalling no more than two to four hours annually), there would appear to be no significant health risk to the population beyond the buffer zone.

In closing, I think it should be emphasized that the static tests will be infrequent, spaced weeks or months apart, and that even the cumulative concentration of these compounds that may precipitate out is likely to be exceedingly small. To this reviewer, it is unfortunate that a less controversial test site was not chosen originally, such as immediately on the seacoast where prevailing winds would have blown the plume out to sea and where any fallout of aluminum compounds would have had a tremendous water dilution factor in the ocean. If the situation with respect to the compounds referred to earlier in this review is not resolved, such a modification of the plan may prove to be worth considering. Nevertheless, for adequate reassurance to the public, the absence of any effect of acid-coated aluminum oxide would be further reassurance.

Finally, the summary statement as written should be modified:

On page 4-15, line 1, which reads, "Given the alternative theories described above," it should be noted that these alternative theories of infection and trauma are not acceptable. Therefore, the summary might best begin with the sentence, "There is a lack of compelling evidence" I agree with the final two sentences of this paragraph, although, again, this is contingent on demonstration of lack of any significant human effect of acid-coated aluminum oxides.

In the section of summary and conclusions, I would recommend the first sentence on page 4-16 be modified after the word "effects" on line 2, to read, ". . . effects, and is present in the neurofibrillary tangles of AD and PDC, a causal" The sentence which follows introduces elemental aluminum for the first time in this Supplement, and I am uncertain of its relevance at this point in the document.



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April 27, 1990

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Dear Mr. Maier:

I have reviewed the document "NASA: Supplement to the final Environmental Impact Statement, Space Shuttle Advanced Solid Rocket Motor Program, Part 4.0: Human Health Effects," and my comments are listed below. Other minor comments or corrections were made directly on the document, which is enclosed.

General comment: This document summarizes the possible health effects of potential exposure to HCl and aluminum generated by ASRM testing. It is generally well written, though it could benefit from some rewording to eliminate repetitions and redundancy. Most sides of the different issues are discussed, though briefly, because of space limitations. However, in certain instances, small sections should be added and more detail should be given. I hope that, for the sake of completeness and clarity, addition of one or two pages will not cause any problem. The part discussing HCl and HCl aerosols is the weakest, which might be due to a relative lack of information on this topic. However, in my opinion, this section would benefit from some rewriting and the addition of more specific details. The section discussing aluminum toxicity appears more complete, though a few points could be added. Here, however, the task of summarizing the amount of literature available and the different views, is certainly a harder task. In general, the document presents a reasonable and balanced view of the potential scenario involving exposures to HCl and aluminum.

p. 4.4: Some further comments on the basis for the choice of the 1.5 mg/m³ air standard are probably needed. In particular, what were the arguments of the NRC Committee on Toxicology for a 24 h standard that is 10 times higher than the 3 minute standard set by EPA?

- Table 4.1: Concentration of HCl (1 h, 20 km): Should this read 0.023 instead of 0.23?
- p. 4.6: Are there any other, more recent studies, on the effects of chronic HCl exposure in addition to that of Henderson and Haggard (1943)?
- p. 4.6: How good is the evidence of a neutralization of HCl by ammonia present in the mouth and upper airways? Could this ammonia content be altered (decreased) in particular disease conditions or because of other factors (age, smoking habits, etc.)?
- p. 4.7: The reference Thurston and Weldman (1987) is missing from the bibliography.
- p. 4.8: Since from the USEPA document it appears that sulfuric acid aerosols are toxic to adolescent asthmatics at concentrations as low as 0.068 mg/m^3 (USEPA 1989), some quantitative evaluation of the amount of HCl aerosols formed, if any, the amount of HCl "potentially" formed, and the amount eventually needed to cause adverse effects on human lungs should also be included.
- p. 4.8: From my reading of the Amdur and Chen (1983) paper, it appears that there is no effect of ZnO alone (p. 148 and p. 149).
- p. 4.9: Although aluminum oxide does not appear to have strong fibrogenetic properties, a case in the literature suggests that aluminum oxide may lead to fibrosis of the lung. This is based on the finding of Al oxide in the lung of a aluminum smelter worker who died from pulmonary insufficiency and whose postmortem confirmed the diagnosis of pulmonary fibrosis (Gilks, B and Churg, A. Aluminum-induced pulmonary fibrosis: do fibers play a role? Am. Rev. Resp. Dis. 136: 177-179, 1987).
- p. 4-10: The fact that ASRM Test emissions are comprised exclusively of nonfibrous aluminum oxide, should be further stressed. Indeed, it seems clear that the speciation of alumina is of utmost importance in the interpretation of epidemiological studies both related to Alzheimer's disease and lung diseases, because of their different bioavailability potential and differential toxicity (see e.g. in lung, Dinman, 1988, op. cit.).
- p. 4-11: Another apparent flaw of the study of Martyn et al. was that the source for cases for dementia was the centers carrying out the computerized tomography (brain scan). To my knowledge,

not being a neuropathologist, Alzheimer's disease would be conclusively diagnosed only at autopsy. Clinical examination would also require evidence of a deterioration over time.

- p. 4-11: Within the epidemiological studies, the results of case-control studies could also be mentioned. Most of those up to 1985 have been summarized by Rocca, W.A., Amaducci, L.A. and Schoenberg, B.S. Epidemiology of clinically diagnosed Alzheimer's disease. *Ann. Neurol.* 19:415-424, 1986. Unfortunately, these and others do not specifically address the hypothesis of an association between aluminum and Alzheimer's disease. One study (Borenstein Graves, A. A case control study of Alzheimer's disease. PhD. Thesis. University of Washington, Seattle, 1988). found a low increased risk associated with the use of Al containing antiperspirants and antacids, however, the validity of the response was judged dubious by the author.
- p. 4-12: A leading hypothesis of etiology of ALS-PD in Guam is not even mentioned. This involves consumption of seeds of a plant, *Cycas circinalis*, which contain a neurotoxic amino acid (beta-N-methylamino-L-alanine; BMAA). BMAA has been shown to induce a disease in cynomolgus monkeys with features similar to ALS (Spencer P.S. et al. Guam amyotrophic lateral sclerosis-parkinsonism-dementia linked to a plant excitant neurotoxin. *Science* 237: 517-522, 1987). A similar syndrome, known as lathyrism, has also been associated with consumption of the chickling pea (*Lathyrus sativa*) which contains a neurotoxic amino acid (beta-N-oxalylamino-L-alanine; BOAA), similar to BMAA (Spencer et al. Lathyrism: evidence for role of the neuroexcitatory amino acid BOAA. *Lancet* 2, 1066-1067, 1986). Although the hypothesis for ALS-PD has been challenged (Garuto R.M. et al. Cycads and ALS/PD. *Lancet* 2, 1079, 1988; Garruto et al. 1989, op. cit.), it is still far from being discarded, as it offers some good explanation for issues such as latency period and changes in dietary practices (see e.g. Deary, I.J. and Whalley, L.J. Recent research on the causes of Alzheimer's disease. *British Med. J.* 297: 807-810, 1988).

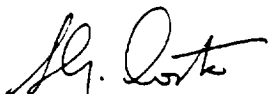
**Additional
Comment:**

An issue that is only briefly mentioned in the document but that could be of importance in elucidating the possible role of aluminum in Alzheimer's disease lies in its effects on the blood brain barrier (BBB) (see Crapper McLachlan et al., 1989, op. cit.) Indeed, aluminum has been shown to alter the BBB function and therefore to enhance the transmembrane diffusion of endogenous and/or exogenous compounds which

might have neurotoxic properties (Banks, W.A. and Kestin, A.J. Aluminum-induced neurotoxicity: alterations in membrane function and the blood-brain barrier. *Neurosci. Biobehav. Rev.* 13:4 7-53, 1989). On the other hand, aluminum appears to have an inhibitory effect of no effect on saturable transport systems (Banks and Kestin, 1989). This aspect of aluminum/BBB interaction should be considered, in addition to the suggested changes in BBB function that would facilitate the uptake of aluminum in the brain.

I appreciate the opportunity to review this document.

Sincerely yours,

A handwritten signature in dark ink, appearing to read 'L.G. Costa', written in a cursive style.

Dr. Lucio G. Costa

LGC/ct
Encl.

